Measuring speech motor skills in phonologically disordered pre-school children and their normally developing peers

Thesis

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MEASURING SPEECH MOTOR SKILLS IN PHONOLOGICALLY DISORDERED PRE-SCHOOL CHILDREN AND THEIR NORMALLY DEVELOPING PEERS

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For Grandma Claire,

who gave me a love of talking.

Introduction

Community based speech and language therapists spend a large proportion of their time working with children who have what is termed a developmental phonological disorder. These children have difficulty acquiring an adequate speech sound system in the absence of known pathology, presenting with unintelligible speech as a result of their pronunciation difficulties. As these children form such an important part of the community paediatric speech and language therapist's case load, a large amount of time has been spent investigating the possible underlying causes of their difficulties, in order to provide the most effective forms of intervention.

In those children who have pronunciation difficulties as a result of physical or physiological abnormality (such as cleft palate or dysarthria) the role of speech motor skill is seen as fundamental when making clinical decisions. This role is not so clear in those children who have phonological difficulties in the absence of known pathology.

It has been demonstrated that speech motor skill develops gradually throughout childhood, reaching adult like levels at around 10 - 12 years of age. Maturation of performance is described in terms of increasing speed, consistency, accuracy and adaptability. (e.g. Kent 1976, Smith 1978, Kent and Forner 1980, Edwards 1992).

Research using speech disordered children shows that at least some such children have poorer speech motor abilities than their normally developing peers in terms of speed, consistency, accuracy and adaptability (e.g. Henry 1990, Edwards 1992, Waters 1992, Towne 1994). Changes in definition and terminology of these speech disordered children leads to some difficulties making cross study comparisons.

A number of direct and indirect techniques can be used to measure speech motor skill, and those measures which can be applied to clinical assessment are given greater emphasis in this thesis. These include measurement of articulation rate and diadochokinetic rate (DDK rate). Research has shown that rate of performance on each of these measures increases with maturity, where increased rate of production is regarded as a reflection of increased motor skill (e.g. Fletcher 1972, Canning and Rose 1974, Walker, Archibald, Cherniak and Fish 1992). There is conflicting evidence concerning the relationship that exists between articulation rate and DDK rate (Haselager, Slis and Rietveld 1991, Yaruss, Logan and Conture 1994). In reviewing the literature it becomes apparent that differences in methodological design may contribute to such conflicting results.

In this thesis, the hypothesis that pre-school children with phonological disorder have poorer speech motor skills than their normally developing peers is tested. In addition to this, consideration is given to the relationship between articulation rate and DDK rate and the development of a clinical method for assessing speech motor skill.

It has become increasingly obvious to the present author that it is crucial to consider carefully the methodologies used to collect and analyse articulation rate and DDK rate data. The exact nature of the speech material to be analysed (e.g. spontaneous versus imitated speech), the techniques used to measure articulation rate (e.g. based on syllables/s or segments/s) and the methods for administering and calculating DDK rate (e.g. the problems with measuring duration using a stop watch) require to be firmly established.

Outline of the thesis

Chapter one considers the justification for and purpose behind measuring speech motor skills in normally developing and phonologically disordered children, definitions of the experimental population and the nature of their speech difficulties. This is followed by a review of the literature on articulation rate and DDK rate studies of normally speaking adults, normally developing and speech disordered children. The hypothesis to be tested in the investigation is derived from this review, and specific research questions are stated.

In chapter two, methodological issues in measuring speech motor skill in young normally developing and phonologically disordered children are explored.

Chapter three describes the method employed in the study, which was designed after taking into consideration those issues highlighted in chapter two. The results of the investigation are presented in chapter four.

In Chapter five, these results are discussed in relation to the hypothesis and research questions defined in chapter one, in particular in relation to detecting an underlying speech motor skills deficit in phonologically disordered children. This is followed by a critical review of the study and directions for future research. Finally, the investigation is summarised and the conclusions stated.

ABSTRACT

Previous research has demonstrated that normally developing children are expected to have adult like control of their speech production skills by 10 years of age, as evidenced by increases in speed of production and decreases in performance variability. (e.g. Kent and Forner 1980). There is also some evidence to suggest that phonologically disordered children may have poorer speech motor skills than their normally developing peers (e.g. Henry 1990, Edwards 1992, Waters 1992, Towne 1994).

There are numerous techniques that can be used to measure a number of different aspects of speech motor control. However, there are methodological difficulties in devising appropriate protocols for the collection and analysis of speed of speech production as used as an index of speech motor skill in young children.

Some of the techniques that have had clinical application include measurement of rate in connected speech production and measurement of diadochokinetic (DDK) repetition rate.

This investigation compared normally developing and phonologically disordered pre-school children on various indirect measures of speech motor skills, in imitated and spontaneous connected speech and in DDK tasks. The investigation also focused on refining the techniques of data collection and analysis appropriate to young children.

While the results vary with regard to the statistical significance of the differences between the two groups of children on articulation rates and DDK rates, analysis of the error patterns in single word, spontaneous connected speech, imitated connected speech and DDK productions identified a sub group of phonologically disordered children who may present with an underlying speech motor deficit as the basis of their phonological disability.

The results of the investigation are considered in terms of their implication for the speech motor skills of the two groups of children, techniques for measuring various aspects of speech motor skill and the clinical identification of phonologically disordered children who have an underlying speech motor deficit.

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Chapter One Investigating Speech Motor Skills in Children

This chapter reviews a number of background issues in investigating speech motor skills in children, with the emphasis placed on reviewing those studies in the literature that have direct relevance to the investigation reported in this thesis.

The development of speech involves the combination of a number of different factors. The importance of speech motor skills in this development is described in section 1.1. The question as to why speech motor skills should be taken into consideration, and more particularly the relevance of measuring speech motor skills in phonologically disordered children is also explored. Section 1.2 considers the various different approaches to measuring speech motor skills, drawing from investigations of adult speakers, normally developing children and phonologically disordered children.

A review of the literature regarding articulation rate and DDK rate in young normally developing and phonologically disordered children is presented in section 1.3. Section 1.4 considers the relationship between these two measures of rate. A chapter summary in section 1.5 provides the basis for the hypothesis and specific research questions of the investigation.

1.1 The importance of speech motor skills in speech development

There are a number of factors that are pre-requisites for the adequate development of language. Locke (1996) highlights factors that are crucial to language development. Spoken communication requires the integration of each of these factors, namely social skill, perceptual skill, neurological development, cognitive ability, linguistic ability and motor skill. This medium of communication is complex, as speech is a rapidly produced act, occurring with little physical effort, despite the complexities contained within each of these components. Moreover, the integration of so many factors in producing speech opens up opportunities for difficulties at any level. For example where a deficiency in one of these areas occurs, speech output can be affected. Aetiology of speech production disorders is a complex area, where a number of underlying difficulties may manifest in the same way. This is particularly the case with difficulties regarding speech sound acquisition. In order to develop the sound system of a child's native language, the child must be exposed to the sounds of the language and have the opportunity to explore their own production abilities in order to produce these sounds. The child must also have developed sufficient hearing and cognitive skills. Thus, it is impossible to completely separate one factor from the other in terms of overall importance in the development of speech.

In the differential diagnosis of children who have difficulties acquiring intelligible speech patterns, each of the above factors is considered in profiling a particular child's difficulties (Deputy and Weston 1998). There is a large corpus of research that addresses perceptual, cognitive and linguistic skills, particularly in the realm of psycholinguistics (e.g. Stackhouse and Wells 1997), that investigates speech perception and speech production. Environmental and social issues that are considered crucial to the development of speech and language are currently being addressed with very young children, for example in the development of screening assessments for the identification of children at risk of developing speech and language difficulties (e.g. Ward 1992). Measurement of the speech motor skills in children with speech production difficulties is however less well defined. With evidence that speech motor difficulties may underpin the difficulties exhibited by some children (e.g. Henry 1990, Waters 1992, Towne 1994) there is clearly the need for greater understanding of how these speech motor skills can be assessed, particularly in the clinical situation. These particular investigations are considered further in section 1.3 below.

The current clinical terminology used to describe children who have difficulties with speech sound acquisition in the absence of known pathological cause is phonological disorder. The children in the current investigation who form the experimental group have each been diagnosed as having a phonological disorder. The following section explores precisely what this term refers to and the types of speech production difficulties these children experience.

1.1.1 Which children fall into the category "phonologically disordered" ?

The term phonological disorder is applied currently to children who "... in the absence of known pathology, do not acquire intelligible speech patterns within the usual time scale". (Lambert and Waters 1995:96).

Earlier terms, such as "functional articulation disorder", implying lack of known cause (Powers 1957) and "dyslalia" (Morley 1972) are found frequently in the literature published before the emergence of linguistic approaches to the study of speech development. "Functional articulation disorder" a term used most widely in the United States, described the speech patterns in terms of four possible types of deviation in the individual speech sounds : omission, substitution, distortion and addition.

"Dyslalia", a term used more widely in the United Kingdom, was defined as : "Defects of articulation or slow development of articulatory patterns including substitutions, distortions, omissions and transpositions of the sounds of speech." (College of Speech Therapists 1960:36). Eventually, the term "articulation disorder" became more widely favoured.

Grunwell (1981:5) discusses how these terms assume that the problem is purely "speech orientated", or phonetically based. She goes on to say that if the disorder is viewed "...not so much one of speech, in the phonetic sense, but one of spoken language, ... the analysis will examine the phonological aspects of the child's speech ". This was suggested by Ingram in the mid 1970's, when he concluded that [functional] articulation disorder shows phonemic rather than phonetic errors, and that the child has a disorder that is of "linguistic origin or phonological type". Ingram in fact coined the phrase "phonological disability", in the child who, differentiated from other children with organic or physiological causes of articulation disorder, presented with phonological dysfunction (Ingram 1976:99).

This radical change in approach led to children, traditionally viewed as having an articulation disorder, as being children suffering from " a linguistic disorder manifested by the use of abnormal patterns in the spoken medium of language" (Grunwell 1981:9). This definition emphasises the fact that the disability is viewed as involving the phonological level of linguistic organisation, not the mechanics of speech production.

This approach to the understanding of children's speech production followed Stampe's (1969) theory of "natural phonology", where in learning to produce adult-like speech sounds, children make substitutions and revisions of their own productions. Stampe suggests that the underlying representations are the same as in an adult, while Ingram (1976) suggests that the perceptual processes whereby children learn to differentiate sounds in adult speech are the same processes they use in producing their own developing speech patterns.

Both Stampe (1969) and Ingram (1976) explain these substitutions in terms of a rule system governing speech production, defined by a number of simplification processes. These processes, that are present in the normal development of child speech fall into two categories, systemic and structural simplification processes. Systemic processes are: velar fronting, palato-alveolar fronting, stopping of fricatives, stopping of affricates, backing of alveolar stops, word final devoicing, context sensitive voicing, liquid/glide simplification and /θ/ - /f/. Structural processes are: initial consonant deletion, final consonant deletion, initial cluster reduction and final cluster reduction.

Grunwell (1981:3) has described the characteristics present in the phonologically disordered child in whom "no detectable major organic pathology underlying the disorder" is present. This notion of lack of known cause parallels that in the definitions of "functional articulation disorder" above. Grunwell (1985) goes on to suggest that following assessment, children will present with either delayed (but normal development), uneven development or deviant development. Children classified in the first two categories would be considered to have a phonological delay, while children in the latter category a phonological disorder. Thus clinical decisions can be made regarding the relative severity of a child's phonological delay/disorder. However, since "phonologically disordered" is used widely in the clinic to refer to children who have not acquired appropriate speech sound patterns in the usual time scale, it has been this term that has been used to describe the children in the reported investigation. A full list of the characteristics typical of the child with phonological disorder are given. These are shown in table 1.1 below.

The term phonological disorder is applied to a whole range of children with speech sound difficulties in the absence of known pathology and implies that these children have difficulties at the phonological level. The only difference between the two terms, articulation disorder and phonological disorder (from the definitions above) appears to lie at the level at which the disorder is placed : phonological or articulatory. It is clear that regardless of the underlying aetiology, both functional articulation disorder and phonological disorder may manifest in the same perceptually identifiable errors. While it is not disputed that at least some of these children may indeed have difficulties at the phonological level, it is possible that some of these children do not, or in addition may have difficulties that, while they can be described at the phonological level, may be articulatorily or motorically based. This is particularly apparent in the clinical setting where for example, intervention aimed at the phonological level needs to be supported by intervention at the articulatory / motor level.

(i)	almost completely unintelligible spontaneous speech, resulting primarily from consonant deviations;
(ii)	child is usually over 4 years of age (i.e. past the age at which speech is normally intelligible to persons from outside the child's immediate social environment. This implies that the phonological system of the language has largely been acquired at this age by the child whose speech and language is developing normally; only a few aspects of the phonology remain to be mastered, though considerable articulatory maturation occurs after this age);
(iii)	normal hearing for speech;
(iv)	no anatomical or physiological abnormalities of the speech producing mechanism;
(v)	no detectable neurological dysfunction relevant to speech production;
(vi)	intellectual abilities adequate for the development of spoken language;
(vii)	comprehension of spoken language appropriate for mental age;
(viii)	apparently well-developed expressive language abilities in terms of range of vocabulary and utterance length (this latter presumably reflecting syntactic structure, which cannot be accurately assessed because of the unintelligibility of the speech).

Table 1.1 *Characteristics of phonological disability. From Grunwell (1981:3/4)*

1.1.1.1 *Sub-classifying phonologically disordered children*

Other researchers use the term "phonological disorder" as a label describing all children with abnormal speech development in the absence of known pathology. Furthermore, within the broad definition "phonological disorder" there have been attempts to provide more detailed sub-classification of affected children by Shriberg and Kwiatkowski (1982) and Dodd (1995) for example, where the issue of whether the speech patterns are typically delayed or disordered are explored.

In Shriberg and Kwiatkowski's (1982) sub-classification system the authors use the term phonological disorder as the generic descriptor of all children with pronunciation difficulties. Within this description children have either a developmental or a non-developmental phonological disorder, where non-developmental refers to acquired disorders such as those evolving as a result of non-developmental changes in orofacial structure. The term developmental phonological disorder is then sub-divided into two categories, delayed phonological development versus residual phonological errors, where residual errors represent those persisting errors that extend beyond the developmental period in children over 7-8 years for example. Severity of phonological disorder is considered in terms of phonological rules, segmental and suprasegmental features of the speech output. Aetiology is explored in terms of three factors that contribute to phonological disability, namely mechanism factors such as hearing and speech production skills, cognitive-linguistic factors and psychosocial factors. The authors then summarise the difficulty in terms of whether or not the child has delayed or residual phonological disorder, the severity of the disorder and its underlying aetiology. This approach is considered a valuable clinical technique that can be used to assist in the management of the phonologically disordered child.

While the four crucial areas that require addressing in understanding the nature of a child's pronunciation difficulty, namely age of onset, severity, aetiology and symptomatology are covered by Shriberg and Kwiatkowski (1982), Dodd (1995) extends this in describing four sub-categories of speech disorder.

In this classification system, children who have an *articulation disorder* are those children who are unable to "produce a perceptually acceptable version of particular phones, either in isolation or in any phonetic context" (1995:54). Children with *delayed phonological acquisition* are those children who present with speech patterns typical of younger normally developing children. Children with *consistent deviant disorder* are those children whose pronunciation patterns can be described by one disordered phonological rule. Finally children with *inconsistent disorder* are those whose productions cannot be explained by a complex phonological rule and when probed on a test of consistency of production produce more than 40% of twenty five test words differently on at least two occasions. The validity of this scoring system can be questioned. For example in Scottish English some of the test items used to calculate variability may yield inconsistent productions in adult speech, where "girl" may be produced as [gɪrəl] on one occasion and as [gɪrl] on another. Devoicing the initial velar in connected speech as in [g̊ɪrəl] or [g̊ɪrl] would be equally acceptable in some contexts and not necessarily indicative of deviant production. Thus the issue of how to address relatively minor phonetic deviations in child speech is raised in the context of this sub-classification system.

While the value of analysing child speech using a detailed approach such as that proposed by Dodd, where spontaneous connected speech and single word utterances are collected from young children, is not questioned, there is some doubt as to whether children with phonological disorder can be categorised in such a manner, particularly since there may be some element of overlap among the categories. For example, while a child with unintelligible speech patterns of no known origin falls into Dodd's *articulation disordered* category, it could be argued that this child's pronunciations are also representative of *delayed* or *consistent deviant phonological development*, where the child habitually substitutes one sound for another.

The crucial focus of investigation in the child who has a pronunciation disorder of unknown origin is the underlying deficit or deficits contributing to the unintelligible speech output. This is particularly the case when designing an appropriate intervention procedure. Thus the term phonological disorder can be considered an umbrella term used to describe developmental pronunciation difficulties that may be either delayed or deviant and detailed assessment must be used to determine the underlying deficit(s). It is within this context that the children with speech production difficulties studied in the reported investigation have each been labelled phonologically disordered.

Since speech is a motor act, the issue of measuring speech motor skills in young children with phonological disorder is a necessary focus of assessment. The question is therefore, how to measure speech motor skills in phonologically disordered children in order to identify those children who may have an underlying speech motor difficulty affecting their phonological development.

1.2 Measuring speech motor skills in children and adults

A number of techniques have been used to measure speech motor skills. In the sections that follow, the reader is directed to a brief overview of the main techniques used to measure speech motor skills, with a summary of their main contributions to the field.

Both instrumental and non-instrumental techniques have been used to measure speech motor skills in adults and children. Each of these broad categories is considered briefly in the sections that follow.

1.2.1 Instrumental techniques

Instrumental techniques fall broadly into two categories: those investigations that involve the direct physiological measurement of the activity of the articulatory mechanism, and those investigations that use acoustic analysis to infer level of speech motor skill. Tables 1.2 and 1.3 below show a summary of direct investigation of articulatory movements. In table 1.2 techniques used to image the vocal tract are described while in table 1.3 techniques used to measure movement patterns are described. The reader is directed to Stone (1991) and Hardcastle (in press) for a fuller description of these techniques.

Studies which have employed these techniques (usually investigations are cross-sectional in design) have shown that there are differences between the way adults and children of various ages perform on the various measures taken. These findings have been interpreted in terms of the overall speech motor skills of children and adults, where it has become generally accepted that younger children have poorer speech motor skills than adults. A gradual progression towards adult like levels is observed throughout childhood.

For example, an investigation using the imaging technique of ultrasound, measured tongue dorsum velocities of eleven children aged 3;3 to 11;6. The findings show that the younger children had slower tongue dorsum movements than the older children (Ostry, Feltham and Munhall 1984).

Type of study : Imaging techniques		
Technique	**Method**	**Comments**
X ray	X rays produce images of the tongue, lips, jaw and velum, usually while stationary.	The harmful effects of radiation limit the use of X ray. However, X ray imaging has been used to provide models of the vocal tract.
X ray microbeam	X ray microbeam targets small, specific areas of the vocal tract. These areas are highlighted using gold pellets.	There is scope for increased used of the X ray microbeam, though this very expensive equipment is not yet widely available.
CT Scan (computerised tomography)	X rays are used to image very thin slices (about 2mm) of tissue. Digital analysis of a series of scans produces a sharp, composite image.	This equipment is not suitable for real time speech as it samples single frames only. The image is limited to transverse and oblique planes. There is however scope for development in imaging the whole vocal tract.
MRI (magnetic resonance imaging)	This technique uses radio waves to image sections of tissue.	Radio signals are weak, and this leads to a slow sampling rate. The sections imaged are not as narrow as in CT scanning. This technique can be uncomfortable for the speaker. There is scope for further development.
Ultrasound	Sound waves are used to produce an image, usually of the tongue.	It is difficult to see the tongue tip due to air in the vocal tract, and structures beyond the tongue cannot be seen. This is however a fast procedure, that is not hazardous, and has been used to map complex tongue movements.

Table 1.2 Imaging techniques used to measure articulatory movements directly

Investigations using movement transduction and point tracking techniques (see table 1.3) have shown similar patterns in development of speech motor skill.

Type of study : Movement transduction and point tracking		
Technique	**Method**	**Comments**
Strain gauge transduction	This system is used to measure lip and jaw movements using miniature gauges to which rigid wire is attached. This wire is attached to the midline of the structure under observation. Movements cause the wire to move, and the tension created during these movements is converted into velocity and acceleration data of the particular articulator.	This technique has been used extensively with child speech to show the differences between adult and child movement patterns. There are distinct differences in these patterns that are attributed to maturity of speech motor control.
EMG (Electro-myography)	Electrodes measure directly the electrical activity of a muscle (e.g. the tongue). This system can be used to demonstrate underlying motor control difficulties in normal and pathological speech.	The electromagnetic signal is rather noisy and difficult to interpret. The procedure can be uncomfortable for the speaker, and is not conducive to the study of child speech.
EMA (Electro-magnetic articulometry)	Small coils are attached to the mid-line of the tongue, lips, jaw and velum. Movements are tracked as the coils move through an electromagnetic field. Analysis using PC software allows interpretation of the tongue movements in real time speech.	This specialised equipment is not widely available. The lengthy procedure which can be rather uncomfortable for the speaker, is not conducive to the study of child speech.
EPG (Electro-palatography)	An artificial palate is used to map lingual-palatal contacts in connected speech.	This procedure is used extensively with older children and adults, both in research and clinical practice, to assist in assessment and treatment. The main drawback lies in that the system does not show what the tongue is doing when it does not make palatal contact. (For example, the tongue may be elevated while no contact is made).
Bite-block studies	This technique measures articulatory compensatory ability through restricting mandibular movements and observing the speaker's ability to achieve the same acoustic end result. Movement is restricted using a bite-block.	There are some methodological differences in the investigations available in the literature, where in some cases individual bite-blocks have been made to fit subjects, while not in others. This makes cross-study comparison difficult. The technique has however been used extensively with children.

Table 1.3 Movement transduction and point tracking techniques used to measure articulatory movements directly

For example, using the strain gauge transduction technique (see table 1.3) research has shown that older children are able to exert greater control of movement of the articulators than younger children (Watkin and Fromm 1984) and that increases in speed of articulatory movement and decreases in variability of speed of movement on repeated experimental utterances are associated with age (Sharkey and Folkins 1985). Sharkey and Folkins propose that there are three processes in the maturation of the speech motor mechanism:

the motor system is organised to produce relatively consistent movements by around 4 years; these movements are then refined by around 7 years, evidenced by a decrease in variability in speed of performance. This variability further reduces up to around 10 years when adult like performance in terms of speed and variability is expected.

Similarly, bite-block studies (see table 1.3) have shown that children's ability to demonstrate motor equivalence (articulatory compensatory ability) develops with age, where increased speed of performance and decreased variability over repeated trials occurs with maturity (e.g. Smith and McLean-Muse 1987, Baum and Katz 1988).

Studies using electropalatography (EPG) (e.g. Gibbon 1990) demonstrate the use of this measurement technique to supplement perceptual observations of speech development. In this study, two children with phonological disorder (aged 4;10 and 6;2) were investigated using EPG to observe the tongue pattern contacts of their speech. The alveolar stops produced by the younger child were perceived as velar stops. However, the EPG patterns showed that the tongue contact patterns for alveolar targets was different to that for velar targets, indicating that while the child was not successful in marking a perceptual distinction between alveolar and velar stops, she was able to execute different motor plans for each of the targets in an attempt to realise the sounds contrastively. The presence of this "covert contrast", where there is evidence of a contrast between two sounds that is not audible, was interpreted in terms of speech motor skill, where there appeared to be a critical difficulty in the fine timing and co-ordination required in the release phase of the alveolar stop. This was in contrast to the elder subject, whose alveolar and velar stops were perceived as correct, with the tongue contact patterns indicating greater motor co-ordination. Thus this technique can be used to measure directly the articulatory patterns of young children for comparison with the perceived productions. Inferences with regard speech motor skill can be made from this technique.

Instrumental acoustic analysis of speech from children and adults has found similar evidence of the development of speech motor skill. These investigations, which have used acoustic analysis techniques to measure various parameters of a recorded speech signal, also indicate that speech motor skill matures gradually throughout childhood.

A brief overview of some of these studies is shown in table 1.4 below. These main studies have collected various single word and connected speech utterances and used acoustic analysis techniques to measure a number of parameters of the speech signal. In terms of speech motor skill, a number of features on the speech signal have been measured, including analysis of fundamental frequency, vowel formant characteristics, voice onset time (VOT), phrase duration and segmental durations. These studies have collected repeated tokens of single word and connected utterances, and compared the duration measurements across various age groups.

Study: Eguchi and Hirsch 1969		
Subjects	**Data**	**Main findings**
84 normally developing children aged 3 - 13 years.	Various single word and connected speech utterances Acoustic analysis of fundamental frequency, formant patterns and voice onset time (VOT) values.	Intra-subject variability of temporal features decreases with age, with adult like performance expected by around 12 years. Intelligibility increases with age, with adult like patterns by around 8 years.
Study: Kent 1976		
Subjects	**Main findings**	
Tutorial paper - a summary of acoustic studies	Kent suggests that timing is the most crucial factor in skilled motor performance. This is evidenced by studies of vowel and consonant durations, where variability of durations decreases with age, while speed increases. Kent notes that speech motor skill continues to improve long after the phonetic skills of the child have stabilised, with adult like performance being achieved at around 8-12 years of age.	
Study : Hawkins 1973		
Subjects	**Data**	**Main findings**
Seven normally developing children aged 4-7 years. Adult data drawn from Haggard (1971)	CCV, CCCV and VCC consonant clusters in various real words. Analysis of segment duration and variability	Within this age group Hawkins did not observe any great changes in duration or variability.
Study : Hawkins 1979		
Subjects	**Data**	**Main findings**
Five adults and seven normally developing children aged 4-7 years (data reported in Hawkins 1973). Six of these children were re-recorded fourteen months later.	CCV, VCC and CV combinations comparing the same clustered and un-clustered consonants. Analysis of segment duration and variability	Hawkins noted that the older children had patterns similar to adult speech, where they imposed more organisation on the segmental structures while the younger children did not. The children tended to achieve more adult like patterns over time, indicating an increase in motor control with maturity.
Study : Kent and Forner 1980		
Subjects	**Data**	**Main findings**
Four groups of ten subjects aged : 4 years, 6 years, 12 years and one group of young adults	Twelve randomly ordered imitated sentences Acoustic analysis of segment and phrase durations	Kent and Forner note an increase in speed and a decrease in variability associated with age.
Study : Tingley and Allen 1975		
Subjects	**Data**	**Main findings**
Twenty-two normally developing children aged 5;0 years to 11;5 years	Maximum repetition rates for 18 CV, and CCV combinations Imitated connected speech (thirty sets) Finger tapping tasks	Tingley and Allen note an increase in speech timing with age, consistent with general neurological development and fine motor skill development. They propose that this timing is adult like at around 11 years of age

Table 1.4 A selection of acoustic studies of aspects of speech motor control

From those studies which have used acoustic analysis of the speech signal, there have been a number of findings relevant to the understanding of speech motor skill. One of the main findings is that there is an inverse relationship between speed and variability, whereas speed increases with age, variability over a series of repeated trials decreases. This is seen to be a direct result of the maturation of speech motor skills and the speech production mechanism, and can be construed to reflect levels of maturation of speech motor skill. Measures of intrasubject variability which tend to indicate that younger subjects are more variable than adult speakers are interpreted an indication of less mature speech motor skill. (e.g. Eguchi and Hirsch 1969, DiSimoni 1974a, 1974b, 1974c, Kent 1976, Hawkins 1973 and 1979, Macken and Barton 1980, Tingley and Allen 1985, Chermak and Schneiderman 1986, Crystal and House 1988a, 1988b, 1990, Smith, Kenney and Hussain 1996).

Similar evidence from studies of children with speech difficulties, which tend to be comparative in nature, have revealed differences in various temporal features between an experimental group and normally developing controls. For example, Stark and Tallal (1979) report that a group of children diagnosed with developmental dysphasia, who had difficulty perceiving the voicing distinction were also unable to make an acoustic distinction between voiced and voiceless stop consonants, unlike their normally developing peers. These children presented with the abilities to convey the features marking voicing distinction (e.g. vowel duration and VOT) that were similar to younger normally developing children. This was interpreted as evidence that these speech impaired children had speech motor skills equivalent to that of younger children. The fact that these children were not yet at a stage where they could distinguish the two voicing conditions would lend itself to the premise that they may not be expected to produce such a distinction. However, it is clear that these children were also not motorically able to produce the distinction, evidenced by the VOT values, and their inability to produce a voicing distinction cannot be explained only by their lack of perceptual ability.

Weismer and Elbert (1982) studied segmental durations of a group of children aged 4;3 - 6;0 who presented with /s/ misarticulations. Using repeated nonsense tokens, the study compared the duration of the fricative /s/ in various phonetic contexts, the authors found that the children who misarticulated the /s/ in their natural speech had longer /s/ segment durations than those who had no difficulty producing the /s/ naturally. If speed of execution is regarded as indicative of speech motor skill then it can be inferred that the children with /s/ misarticulations had poorer speech motor skills than their normally developing peers.

Catts and Jensen (1983) in their study of phonologically disordered children found similar evidence of longer segmental durations in comparison to normally developing children, indicating that "....some phonologically disordered children may have less mature neuromuscular control for speech than do same aged normal children" (1983:507). Their study of nine phonologically disordered children aged between 3;10 and 5;7 years and age/sex matched normally developing children, measured VOT, vowel duration, consonant closure duration and duration of voicing of stop consonants in various syllable initial and syllable final positions. The findings of this study showed that the experimental group had longer closure duration and less voicing during consonant closure than the control children in word final stop consonants. These findings indicate that the experimental group were less able to control the laryngeal gestures in sustaining voicing of the target consonants. In the VOT data for word initial stop consonants, the phonologically disordered children could either make a distinction between voiced and voiceless stops or produced the voiceless stops with a short lag associated with voiced stops. This latter, "non-contrastive" group represents the stage of the production of normally developing children at a younger age (Macken and Barton 1980) and it can be concluded therefore to be indicative of immaturity of speech motor skills. This explanation is reached on the basis that short lag (and therefore voiced) stops require less laryngeal co-ordination and are easier to produce. This indicates that the production of a voiced stop requires less skill than a voiceless stop which requires longer voice onset time. Thus, the production of voiceless stops is indicative of maturity of speech motor skill.

While an increase in speed is seen to be commensurate with a decrease in variability over repeated productions of a token, Catts and Jensen found that phonologically disordered children differed only in terms of rate and segment duration from their normally developing peers. They did not however find a difference in the variability of the productions between the two groups of children. This finding is also reported by Waters (1992) in a study of normally speaking adults, normally developing and phonologically disordered children.

Thus, while measuring temporal variability is indicative of speech motor skill, since normally developing and phonologically disordered pre-school children tend to have similar degrees of variability, while phonologically disordered pre-school children have significantly slower segment durations than their normally developing peers, leads to the conclusion that in young children, measures of rate are more sensitive than measures of variability.

1.2.2 Non-instrumental techniques

Non-instrumental techniques for measuring speech motor control include those which attempt to observe oromotor function. This type of measurement is made most frequently in the clinical setting, in order to evaluate the oromotor skills of a client. Clinical evaluation of oromotor function forms an integral part of speech and language assessment to assist in differential diagnosis of a child's speech and/or language disability.

While published protocols exist for such assessment (e.g. Robbins and Klee 1987), it is possible to carry out an informal assessment of the various aspects of oromotor function, including evaluation of general head and neck appearance, articulatory movements (lips, tongue, palate etc.), performance on diadochokinetic tasks which involve rapid repetitive and alternating movements, breathing control for speech, oral sensation and oral form perception.

In one published protocol for oromotor function (Robbins and Klee 1987), these aspects are considered in terms of structure and function. The protocol, devised from a study of 90 children aged 2;6 -6;11 (10 in each of 9 age ranges) found a developmental increase in functional performance, which is most dramatic between the ages of 2;6 and 3;11. The children then develop more gradually towards adult patterns, similar to that noted by Sharkey and Folkins (1985) in the ability for children to refine motor skills over a period of time.

One aspect of this protocol is the collection of diadochokinetic data (hereafter referred to as DDK) and calculation of DDK performance as a rate measure, i.e. the maximum rate at which the articulators can produce alternate movements, usually in non-meaningful productions. From the normative data provided in the protocol, there is a clear developmental trend for increase in DDK rate with age in normally developing children.

While this protocol provides some suggestions for the collection and interpretation of DDK rates, other published oromotor function assessments (e.g. Fletcher 1972, St Louis and Ruscello 1987) use different procedures. This discrepancy in the various published protocols for the collection and interpretation of DDK rate data is considered in more depth in chapter two. Studies which have used DDK rates are discussed further in section 1.3 below.

1.2.3 Using instrumental and non-instrumental techniques in measuring speech motor skills in young normally developing and phonologically disordered children

The variety of techniques available, both instrumental and non-instrumental in nature, each have value in furthering knowledge regarding the development of speech motor skills. As described above, studies which have used instrumental techniques show that there is a developmental maturation of speech motor skill throughout childhood until adult like patterns are observed. The precise age at which it is suggested that adult like patterns are expected differs, depending upon the results of various investigations.

For example, the findings reported in studies of articulatory compensatory ability, using either a strain gauge transduction or a bite block system give conflicting reports with regard the age at which children can compensate as well as adults. Smith and McLean-Muse (1986) and Baum and Katz (1988) suggest that children as young as 4 years can compensate like adults, while Edwards (1992) suggests this ability is not adult like until around 12 years of age. This disparity may be attributable to methodological differences, where some studies prepare well fitting, tailor made apparatus that is used to measure compensatory ability (i.e. a fitted bite block) and some do not. Ages of subjects and in particular the speech data collected differs between studies, with consonant production and/or vowel production studied. The one consistent finding that these various studies have in common is the decrease in variability of productions of repeated tokens of speech data that occurs with maturation.

Evidence from acoustic analysis of speech data can supplement the findings of studies of articulatory compensatory ability because, "as an individual develops the ability to use different articulatory gestures to produce the same acoustic output, acoustic variability should decrease as variability in vocal tract shape decreases" (Edwards 1992:190). The main findings from acoustic studies indicate gradual maturation of speech motor skill towards adult like ability which can be expected between the ages of 8-12 years (Eguchi and Hirsch 1969, Kent 1976, Tingley and Allen 1975).

In designing an experiment to evaluate differences in speech motor skills between two groups of pre-school children, a number of issues with regard instrumental investigation are posed. The advantages to using instrumental techniques are those concerned with the objectivity of measurement and the standardisation of procedures. However, with young children using various instrumental techniques can be invasive and could potentially inhibit natural speech production. This is particularly the case with those imaging techniques which are hazardous. In the case of bite-block and strain gauge investigations the equipment may appear frightening to young children. EMA and EMG studies can cause discomfort to adult speakers, thus their suitability to the study of child speech is questionable. The use of EPG is growing, with its clinical use giving encouraging results in the assessment and treatment of a variety of developmental pronunciation difficulties (e.g. Gibbon, Dent and Hardcastle 1993, Friel 1998). However, with young pre-school children, where an EPG palate must be custom made for each child, the fitting of an EPG palate can be intimidating to a child as young as 3 years of age. Additionally, with the young child there are problems of rapid changes in the shape and size of the oral cavity that may affect the use of an EPG palate.

Thus, many of the instrumental techniques that can measure directly aspects of speech motor skill may not be suitable for use with young children. Since acoustic analysis of speech production produces information about the development of speech motor skills from a recorded speech sample, it is this technique that is considered the most appropriate for this population of children. The data that is collected for subsequent acoustic analysis can range from single words to connected speech utterances. Recording of this data must be of the highest quality, and anyone with access to high quality recording equipment such as digital audio taping can record data for subsequent analysis.

Analysis of this data can be carried out on any of an increased variety of software programs displaying waveform and spectrographic information from the pre-recorded speech signal. Furthermore, it is possible to use this type of software to analyse data that has traditionally been analysed using non-instrumental techniques, such as DDK data.

Furthermore, when analysing speech using acoustic analysis techniques a variety of different speech samples can be collected including single word data, connected speech data and DDK repetition data. Acoustic analysis to yield articulation rate and DDK rate measures of speech affords one of the least invasive methods of assessing speech motor skill. Since speed is regarded as an indication of maturation of speech motor skill, then it can be deduced that measuring the rate of various aspects of speech production in children can provide indirect information about the level of speech motor skill. The use of articulation rate and DDK rate measures is relevant in both clinical and research environments.

In the following sections the findings of previous research using articulation rate and DDK rate measures in young normally developing children, adults and speech disordered children are explored.

1.3 Articulation rate and DDK rate in young normally developing children, adults and phonologically disordered children

In the sections that follow, those studies which are closely related to the reported investigation are reviewed. Studies of normally developing children and adults are considered first, followed by studies of children with various types of speech disability.

1.3.1 Normally developing children and adult speakers

Most investigations of rate of speech production in normally developing children using both perceptually and acoustically based analysis have shown an increase in rate associated with age. The rate of production in connected speech can be measured using articulation rate, usually in segments/s or syllables/s. Some studies refer to this as speech rate, while some distinction between these two measures can be made. While speech rate is calculated on stretches of speech that may or may not contain pauses, articulation rate is calculated on stretches of speech free of pauses greater than 250ms. This duration is prescribed as any periods of silent interval of less than 250ms could reflect articulatory closure associated with producing the articulatory gesture. These two measures of rate of speech production and the effects of pause durations are considered in greater depth in the discussion regarding methodologies in chapter two, section 2.1.3.

In the studies of speech production in young normally developing children, this distinction is not always made apparent, and at times the two terms are used interchangeably. In the current investigation, only the term articulation rate is used. Where a study cited has included pauses in the overall rate measure, this is stated.

While articulation rate measures the rate of production in connected speech, other measures have been used both in research and clinically, to measure the rate of production of repetitive, alternating movements of the articulators. This measurement, DDK rate, has also been shown to increase with maturity. In the following sections, the reader is directed to a review of the pertinent literature regarding the development of articulation rate and DDK rate in children.

1.3.1.1 *Articulation rate in connected speech data*

As segment durations decrease, total phrase duration decreases, (where pause duration is equal). This leads to an increase in the calculation of articulation rate in segments/s or syllables/s (e.g. Kowal, O'Connel and Sabin 1975). The ease with which an estimate of articulation rate can be achieved without sophisticated equipment allows it to be used widely in the clinical setting.

Various investigations have used articulation rate as an indication of speech motor skill and as such have demonstrated that articulation rate is affected by a number of variables. These include linguistic and cognitive variables (e.g. Hawkins 1971); utterance length (e.g.

Malécot, Johnson and Kizziar 1972); speaking context (e.g. Duchin and Mysack 1987) and age (e.g. Smith, Wazowicz and Preston 1987).

Some of this research has suggested that elderly adult speakers tend to have longer segment, syllable and sentence durations than younger adults and that children tend to have longer segment, syllable and sentence durations than adults (Smith et al 1987). These results suggest that as articulation rate is an indication of speech motor skill, and motor skills change through maturation, increased articulation rate is associated with maturation of speech motor skill and decreased articulation rate in late adulthood with deterioration of speech motor skills associated with normal ageing, assuming there are no other pathological indications.

In a large scale investigation, Amster (1984) measured articulation rate in 120 normally developing children. There were twenty children (ten boys and ten girls) in each of six age ranges : 2;6-2;11, 3;0-3;5, 3;6-3;11, 4;0-4;5, 4;6-4;11 and 5;0-5;5 years.

Amster tape recorded each child in conversation and selected ten utterances for analysis. An utterance was defined as a continuous stretch of at least two words which did not contain an audible breath. Utterance boundaries were defined by a gap of at least 250msec. Amster chose utterances of varying length for analysis, in order to gather examples of short, medium and long utterances. Each utterance was transcribed and the duration measured using a stopwatch. The number of syllables in each utterance was noted. To ensure reliability, utterance duration was recalculated five times. Articulation rate was then derived in syllables/s.

Amster found that utterance length was positively correlated with articulation rate and there was a significant tendency for articulation rate to increase with age. No differences were noted between the sexes. Amster was careful to consider the effect of utterance length, but the use of a stopwatch to time utterance duration limits precision when compared to acoustic analysis of duration.

Waters (1992) calculated articulation rate in multiple tokens of an experimental phrase in twelve normally developing children between the ages of 3;8 and 4;10, and twelve normally speaking adults. Twelve phonologically disordered children were also studied in this investigation. This section of the study is considered in section 1.3.2.1 below.

18 tokens of the same phrase were incorporated into three different carrier sentences. These were presented in picture form with pre-recorded spoken material accompanying the illustrations. The subjects were each instructed to listen to and report back on what they had heard, thus delayed imitation was achieved. Spectrographic analysis of this

experimental phrase was used to calculate articulation rate. The results indicated that the articulation rate in segments/s of the normally developing children was significantly slower than that of the normally speaking adults.

Waters suggests that because the child subjects achieve fewer speech segments (and therefore fewer articulatory gestures) per second than the adult subjects this indicates that the children have less mature speech motor skills.

Walker et al (1992) conducted an investigation of articulation rate in 3 and 5 year old children, with normally developing speech and language skills. The study compared articulation rate in the two subject groups in different linguistic contexts, in order to determine whether there was a developmental trend; whether there is a relationship between speaker gender and articulation rate; whether linguistic context affects articulation rate; whether there is a relationship between articulation rate and utterance length; and whether a measure of articulation rate in phones per second (segments/s) and syllables per second yield comparable results.

Forty children provided the speech data for the study. Twenty were aged 2;11 to 3;2 and twenty were aged 4;11 to 5;2. None of the children had any history of speech, language or hearing difficulty.

A screening test battery was administered to each subject, assessing speech and language skills. Three types of speech samples were then elicited and audiotaped. The first sample consisted of spontaneous speech in a story-telling task. Two imitated speech samples were then elicited, by instructing each child to repeat one long and one short utterance (predetermined) presented by the investigator and one long and one short utterance taken from the child's own spontaneous speech sample.

Spectrographic and statistical analysis of the results yielded significant effects of age and linguistic context on the mean number of syllables and the mean number of phones within the utterances. The 5 year old children presented with significantly longer "runs" than the 3 year old children. Imitated speech had significantly longer runs than spontaneous speech. There was greater temporal variability in spontaneous speech than in imitated speech; and a significant correlation was found between articulation rate in segments/s and in syllables/s.

The authors conclude that their study indicates a developmental trend of increased articulation rate with age. They note however that there may be a number of factors contributing to this effect, including the attention given by each child in the imitated tasks, and the rate of the experimenter's speech. These conclusions complement those drawn by

Waters (1992) and it is therefore necessary to ensure consistency in imitated tasks by using pre-recorded presentation.

However, this observation that articulation rate increases with maturity in normally developing children is not noted by Pindzola, Jenkins and Lokken (1989). In their study of thirty normally developing children at three age levels, no significant increase in articulation rate was found. Ten children in three age ranges (3;0-3;9, 4;0-4;9 and 5;0-5;9) provided the connected speech data. This data consisted of a story telling task and answering open ended questions.

Speaking rate and articulatory rates were evaluated for each child, where the former included hesitancies and pauses while the latter represented a sample of fluent speech. The measures were expressed in syllables/minute as opposed to syllables/s. All the rate data were evaluated using a stop watch.

The authors conclude that in their study there is no significant increase in rate associated with age, when measured using the more demanding context of spontaneous speech production (as opposed to imitated speech). However, the finding in this investigation does indicate that while speed of production is considered to be an indication of level of maturity of speech motor skill, the age at which changes are observable may vary in normally developing children. Perhaps by considering the accuracy of the developing children's speech patterns further interpretations could have been forthcoming.

Furthermore, when assessing the articulation rate of any speaker, it is not simply a matter of speed and accuracy of motor execution. In planning the utterance, the speaker uses a number of other operations including linguistic accessing of the message and cognitive planning skills. By accessing the desired utterance, and then executing it in a motor plan, a speaker who has lexical retrieval difficulties may present with a slower articulation rate that is not due simply to immaturity of motor control. It is for this reason, that articulation rate in connected speech can only be considered to be one means of assessing the motor skills required for speech. In assessing the speed of DDK repetitions of non-meaningful CV sequences, this problem can, to some extent, be addressed.

1.3.1.2 *DDK measurements*

Both Fletcher (1972) and Canning and Rose (1974) comment that speech is a highly integrated physiological act in which rapid movements of the articulatory organs are necessary for efficient speech production. DDK rates are collected by asking the speaker to repeat the same non-meaningful syllable or sequence of syllables many times as quickly as possible. For example, the speaker would be asked to repeat a simple CV syllable such as /pə/[1] as quickly as possible, producing the consonant clearly each time with the resultant utterance: /pəpəpəpəpəpəpəpəpə/. Alternatively, the speaker could be asked to produce a series of different CV syllables requiring the alternating of place of articulation as in: /pətəpətəpətəpətəpətə/ or /pətəkəpətəkəpətəkə/.

Fletcher (1972) investigated DDK rate, and in particular the problems facing those measuring it using the count-by time technique. This somewhat cumbersome technique requires the tester to measure how many repetitions are produced in a set period of time. Fletcher was successful in adapting this to a more easily accomplished technique, yielding similar information, where the assessor establishes the length of time it takes the subject to repeat a set number of syllables (time-by-count). This investigation also provides normative data on the development of DDK rate.

Fletcher's (1972) large scale investigation involved collecting DDK rates from 24 boys and 24 girls at each age level between 6 and 13 years of age. Each child was instructed to try and say some strings of syllables, as fast and for as long as they could. The monosyllables /pʌ/, /tʌ/, /kʌ/, /fʌ/ and /lʌ/; the bisyllables /pʌtə/, /pʌkə/, /tʌkə/; and the polysyllabic sequence /pʌtəkə/ were collected for each child. 20 repetitions were required for the monosyllabic utterances, 15 for the bisyllabic utterances, and 10 for the polysyllabic.

Fletcher speculated that the order of presentation may affect an individual's performance due to increasing complexity as the task goes on, thus introducing a training effect. The order of stimuli presentation was therefore varied across the subjects to investigate the extent of this effect, which in fact was not found to be contributory.

A stop watch was used to measure the time taken to repeat the necessary number of syllables, while the data were also tape recorded and analysed using an oscillograph in order to confirm the precise times.

A highly significant trend of increased DDK rate with age was found for each sequence. A significant difference was found between the boys and girls, where the girls tended to be slightly faster in monosyllables and the boys faster in polysyllables.

It is not clear however from the report of the investigation whether any of the children made articulatory errors in repeating any of the sequences of syllables, which, when it is considered that the utterances resemble a kind of "tongue twister", seems highly likely.

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[1] The brackets that should be used when showing non-word productions such as DDK repetitions is contentious. However, for ease of reference, throughout the reported investigation, target productions,

Canning and Rose (1974) observed that much of the literature about oral DDK rates was derived from studies of American children, and it could not be assumed that any of the normative data presented would be applicable to British children. This is especially true where there are differences in consonant realisations between the two accents. For example the Standard American repetition sequence /pərʌkə/ does not equate with Standard English pronunciation as in /pətəkə/, (alveolar stops vs. taps) making direct comparison of the studies difficult.

In Canning and Rose's (1974) study, three hundred children from Southern England provided the speech data. These children were judged by the local school teachers as presenting with average ability and normal speech skills. Speech skills in the children were subsequently screened by the investigators, and those children judged as having a speech difficulty were subsequently excluded from the investigation.

The children were split into groups based on age ranges, each age range containing 50 children, 25 male and 25 female. The first five groups covered the ages from 4;6 to 9;6 and a fifth covered an older group of 13;6 - 14;6. Three tasks were presented to each child, the younger children in groups and the older children individually. The first consisted of silent oral DDK rates (moving the tongue tip from one corner of the mouth to the other, ten times), the second, ten rapid repetitions of each of six consonant sounds (/t/, /k/, /j/, /l/, /w/, /p/) and the third, ten repetitions of a sequence of consonants (/p/, /t/, and /k/). Where the young children found the repetition of the sequence of consonants too abstract, the word "buttercup" was used in its place. It is assumed that in the repetitions of the stop consonants an unstressed vowel such as the schwa was produced as in /pəpəpə/ etc.

The second task was audio recorded while the third was not. Canning and Rose report that all the subjects were able to carry out all the tasks. However, the points raised about mispronunciation in Fletcher's study (1972) above can also be applied to Canning and Rose's study, particularly since the children were younger and may have been more likely to produce developmental pronunciation errors. The effect of replacing the sequence /pətəkə/ with the word "buttercup" may also have altered the comparability of the results. The consonants and vowels in the word do not match the original sequence, due to the fact that the initial stop is voiced in the real word and voiceless in the non word syllable sequence. This mismatch of consonants and vowels may lead to differences in duration as the various consonants and vowels have different inherent durational characteristics. There are three

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whether a real word or a DDK repetition, are shown in slanted brackets such as / /, while the actual realisations produced by the various children in the study are shown in square brackets such as [ ].

stops in the non word sequence, and four in the real word. The actual effect this may have on timing is not discussed, although Canning and Rose do state that "...a few children voiced voiceless plosives which very slightly reduced their speeds." (1974:49), presumably due to the shorter voice onset time (VOT) of voiced stops.

Fletcher (1972) and Canning and Rose (1974) applied slightly different criteria to their respective analyses. Canning and Rose included any pauses for breath in their overall calculation, while this is not clear in Fletcher's investigation. Whether or not the maximum DDK rate is achieved on one breath of air or more is not clear, thus the comparability of the normative data resulting from these studies is debatable.

Further normative data is provided by Oliver, Jones, Smith and Newcombe (1985), Robbins and Klee (1987) and St Louis and Ruscello (1987), the latter two are reported as part of published clinical protocols for DDK rate amongst other oromotor tasks.

Oliver <u>et al</u> (1985) studied two hundred children aged between 8 years and 16 years and 20 young adults on a variety of oral tasks. The authors collected DDK rates from six DDK tasks taken from the Frenchay Dysarthria Assessment (Enderby 1983) and administered according to the protocol in this assessment which, for example, asks the speaker to say the syllables "ka la" 10 times as quickly as possible. A score was evaluated which showed that there was a clear developmental trend for DDK rate to increase with age, with adult like performance gradually appearing after around 12 years of age.

In the protocol described by Robbins and Klee (1987), both monosyllabic and polysyllabic repetition rates are collected together with data on a number of oral motor abilities. 90 children aged between 2;6 and 6;11 years provide the normative data which was collected for the monosyllables /pʌ/, /tʌ/ and /kʌ/, the polysyllable /pʌɾəkə/ and the word "patticake". DDK rate is calculated in repetitions/s produced in a 3 second period.

Although there is a significant developmental increase of DDK rate with age, a number of points with respect to this data can be raised. As in Fletcher (1972) and Canning and Rose (1974), no reference is made to how to score the DDK rates where a child has produced articulatory errors. Though the protocol does allow for noting articulation errors, there is no indication of whether or not the DDK rate should be calculated with or without these errors. The assumption that all of the children in this investigation were able to produce all of the required targets all of the time must be called into question when the ages of the subjects are considered. Although one might expect older children to produce all of the necessary sequences, both in the task and within their own spontaneous speech, the younger children, as young as 2;6 in this study, may not have a stable sound system.

It could be argued that the child who repeats /kʌkʌkʌkʌkʌkʌ/ and mispronounces one or more of the /k/ sounds as a /t/ may in fact present with a different rate were he not to mispronounce, and as such yield inaccurate information about that child's ability to produce repetitive velar contacts. The movements of the tongue to the alveolar ridge from the vowel may take less time than moving from the same vowel to a velar contact, as there is less displacement of the tongue in the former action. Close inspection of the normative data in the studies cited above reveals that overall DDK rate for a /kʌ/ sequence tends to be slower than for a /tʌ/ sequence. It is therefore important that any mispronunciation be considered. The fact that the mean DDK rate for a /kʌ/ sequence is slightly slower than for a /tʌ/ sequence may be attributable to the extent of lingual elevation required to produce a /k/.

In the polysyllabic sequence, the same observation can be made. Where a child mispronounces the sequence /pʌɾəkə/ as /pʌɾətə/ for example, overall DDK rate will not be an accurate measurement of that child's ability to make bilabial-vowel-tap-vowel-velar-vowel movements.

The protocol described by St Louis and Ruscello (1987) also forms part of a complete orofacial examination (Oral Speech Mechanism Screening Examination - Revised, OSMSE-R). 177 subjects provide the normative data ranging in age from 5 years to 77 years. DDK rate in repetitions/s is calculated using the time-by count method for 16 repetitions of the monosyllables /pʌ/, /tʌ/ and /kʌ/, 12 repetitions of the bisyllable /pʌtə/ and for 8 repetitions of the polysyllable /pʌtəkə/. Guidelines are given for converting the time taken to produce the required number of repetitions into a rate in repetitions/s. The authors also note rhythmicity and accuracy of production, however it is not clear whether rate should be evaluated on all productions or accurate productions only. DDK rate was however found to increase with age, with adult like rates achieved at around 13-15 years.

Of these two clinical protocols, only Robbins and Klee (1987) provide normative data for pre-school children. Henry (1990) recognised the need for further normative data for younger children, and in this investigation also studied a group of children with impaired speech. The results of this latter analysis are considered in section 1.3.2.2 below. 60 normally developing children aged 3 - 5 years provided the speech data, which included DDK tasks. Three monosyllabic sequences (e.g. /tə/), six different bisyllabic sequences (e.g. /dʌbə/) and five different polysyllabic sequences (e.g. /kʌpʌtə/) were collected for each child. A total DDK score was calculated in addition to the mean DDK rates for each of the three subtests. It is not clear however from the report of this investigation how DDK score was calculated.

It is important to note once again, that it is not clear if all the children managed to achieve all the DDK targets without mispronouncing any of the syllables, and if not, if this inaccurate data was included in the analysis. Not withstanding these criticisms, Henry does report a developmental trend of increased DDK rate with age.

A recent paper from Towne (1994) does consider accuracy of production in studying the compensatory abilities of children when producing DDK sequences, using a bite-block technique.

In this investigation, thirty children provided the speech data. These children were assigned to one of two groups. 15 children were classified as having normal speech skills for their age, and 15 as presenting with severe phonological disorder. The former group's mean age was 5;0 and the latter 4;11. The results from the phonologically disordered group are considered in section 1.3.2.3 below.

Two speech samples were recorded for each child: one where the child's mandible was free and the other when the mandible was stabilised by a bite-block. Each child was given a model of the speech stimuli before attempting to produce the same stimuli as accurately and as fast as possible. The monosyllables /tʌ/ and /kʌ/ and the bisyllable /tʌkʌ/ were recorded in both speaking conditions. Each sample was analysed perceptually, and any misarticulation transcribed. It was noted that the phonologically normal children presented with no errors in the monosyllabic sequences in either mandible position (free or stabilised), and in the bisyllabic sequence, four children had difficulty producing the sequence in both conditions. Those sequences that were misproduced were excluded from the analysis.

The DDK rates of the remaining correctly articulated sequences were measured in repetitions/s through observation of each sample's waveform on an oscillograph. There were consistently faster repetition rates for /tʌ/ than /kʌ/. This supports the earlier observation of other normative data where the DDK rate for /tʌ/ tends to be faster than for /kʌ/.

Kent, Kent and Rosenbek (1987) provide an overview of DDK rate (described as maximum repetition rate in their paper - MRR). The authors note that although it is clear that DDK rate performance increases with age, it is not clear at which age one would expect the normally developing child to achieve adult-like performance. Fletcher (1972) indicates that the earliest expected would be 15 years, while Canning and Rose (1974) suggest that adult values are reached by around 9 - 10 years.

Kent et al (1987:379) comment that the normative data provided by Fletcher (1972) and Canning and Rose (1974) lacks any information on the variability of children's DDK rates. They suggest that a more robust analysis using acoustic techniques such as spectrographic software should allow for a more "complete analysis of MRR responses ..... in a variety of settings".

This view that the speed with which a speaker produces a DDK sequence provides only a simple, surface analysis of articulatory skill has been considered by Williams (1996). In this investigation, a group of 30 normally developing pre-school children provided a variety of both spoken and silent DDK utterances (such as moving the tongue from side to side). Ten children were aged 3, ten were aged 4 and ten were aged 5, and none had any history of speech, language or hearing difficulties. They were monolingual and were considered to have appropriate speech skills for their age. Williams also presents three case studies of DDK rates in children with impaired speech, the results of which are described in section 1.3.2.3 below.

The spoken DDK tasks included real word repetition, non-word repetition and the repetitions of various syllable sequences. The non-words were derived from the real word stimuli, by maintaining the consonants and changing the vowels, while the syllable sequences were also derived from the real words by substituting the vowels with a schwa vowel. For example, where the real word was "digger"([dɪgə]), the non-word became [dægɪ] and the syllable sequence became [dəgə]. A variety of two and three syllable utterances were compiled, and each child introduced to picture stimuli in a naming task to familiarise them with the real words. The order of presentation of the repetitions was then randomised. Each child was required to repeat the token once after the investigator's model, and then instructed to repeat the same token five times as fast as they could. A stopwatch was used to time each set of five repetitions from the tape recording made of each child's speech data.

Williams devised a scoring system that took into consideration the speed of DDK performance, the accuracy of these productions in both the single imitation and sequence of five repetitions and the consistency with which each child produced the tokens with respect to their own form in the single form imitation.

The findings indicated that the youngest children, while consistent in their productions compared to the single imitation, the two older groups were both more accurate (in comparison to the adult model) and more consistent (with their single imitation).

The value of William's approach in the analysis of DDK performance is that it allows consideration of the relationship between accuracy of repetition of DDK stimuli and a child's habitual realisations of the target phonemes. This type of approach to investigating DDK performance in children who have speech sound difficulties is likely to increase our understanding of the relationship between the oral motor processes used in DDK task performance and connected speech performance.

1.3.2 Phonologically and other speech disordered children

Studies of articulation rate and DDK rate with children with varying degrees of speech and or language difficulties have revealed differences between these children and their normally developing peers. These investigations are considered in the following sections.

1.3.2.1 *Articulation rate in connected speech data*

The investigation by Waters (1992) cited in section 1.3.1.1 above also investigated articulation rate in segments/s of a group of pre-school children with phonological disorder in multiple tokens of the same imitated phrase as the normally developing children. When the results of the data from this group of children were compared to their normally developing peers, the phonologically disordered children had significantly slower articulation rates than the normally developing children.

In an investigation by Campbell and Dollaghan (1995) where the articulation rate of children who had speech and language difficulties following traumatic brain injury (TBI) was assessed, similar findings were revealed, where the children with communication impairment had slower articulation rate than their normally communicating controls. Although this investigation uses children with different pathologies from those with a developmental disorder, the results are useful in observing the differences in articulation rate between normally developing and disordered speech samples.

Nine children with TBI aged 5;8 - 16;2 and nine age and sex matched control children provided the data. This data consisted of spontaneous speech samples in a narrative style. Waveform analyses of this data were used to determine both speech rate and articulation rate in syllables/s.

The authors point out that slowed articulation rate may be a result of either reduced motor control, or cognitive and linguistic influences of the communication impairment, and as such make the distinction in their analysis between speech rate measures (where pause time is included) and articulation rate measures (where pause time is subtracted). Measuring articulation rate was seen as a reflection of articulator speed and speech motor performance, and measuring the frequency and duration of pauses was seen as a reflection of the cognitive and linguistic factors in producing connected speech. The idea that pauses may represent speech processing and planning rather than real time motor activity is logical, if it is assumed that such pauses do not necessarily reflect breathing control alone.

Articulation rate was calculated from the first 50 syllables in one sample of speech recorded. The duration and number of lexical syllables in each run of speech containing pauses no longer than 100ms was determined to give an articulation rate. Each pause longer than 100ms was also measured, giving a within-utterance pause time, that then determined the average amount of silent pauses within each utterance.

In an analysis of the results, three of the children who had already been shown to have reduced speech rate, also had reduced articulation rate. These three children had also been perceived as dysarthric by an independent specialist. The authors suggest that there is a clear implication that there is a motor difficulty in these cases, resulting in overall slowed articulation rate. On the other hand, four of these children had substantially greater pause times, suggesting that cognitive-linguistic factors are contributing to the slowed speech rate. Furthermore, one of the subjects who had substantially greater pause times than the age/sex matched control child, had an articulation rate which was similar to the control. This suggests that in this case, there are cognitive-linguistic factors and not articulation-motor factors contributing to slower speech rate. Of note is the rating of this child as normal and not dysarthric using perceptual-auditory means.

The authors conclude, that although this investigation involved a relatively small number of children, suggestions as to how to separate articulation-motor factors from cognitive-linguistic factors in discussing articulation rate may prove useful. Each of these techniques can be used to help gain greater insight into the articulation rate of children with disordered communication. The use of children with TBI may in fact further complicate the matter, where each child may present with very different difficulties resulting from TBI, causing difficulty in group interpretation of the results. The results of this study however further emphasise the value of using articulation rate as an index of speech motor skill in the speech disordered child.

DDK rate has the potential to provide additional information about the nature of the speech difficulties presented by various speech impaired children. One advantage of DDK rate measures is that the child is free, in such tasks, from the linguistic load required to process a semantically and syntactically accurate utterance and required only to achieve the articulatory planning required to produce that utterance.

1.3.2.2 *DDK measurements*

In 1974, Yoss and Darley presented the results of a study which suggests criteria for the differential diagnosis of children with developmental apraxia of speech. These criteria include the understanding that children with developmental apraxia of speech will have, amongst other speech and non-speech behaviours, slower DDK rates than their normally developing peers. Thus the value of DDK rates in the clinical setting was firmly established, and further research into the DDK performance of various other speech and/or language impaired children followed.

McNutt (1977) presented an analysis of various oral motor behaviours in children with /s/ or /r/ misarticulations, and a group of normally speaking peers. This study compared the performance of three groups of children on a number of tasks including DDK performance. (Described as alternate motion rate - AMR - in his paper).

All the children were aged between 12;7 and 15;4, with fifteen children providing the data for each group. Of the speech impaired groups, one group of children had problems articulating /r/ only, and the other group difficulty with articulating /s/ or /z/.

The AMR tasks involved repetition of one bisyllabic utterance (/dʌgə/) for as long and as fast as possible. The subjects were instructed to take breaths where necessary, and to continue with the repetition of the sequence, until five sections of repetitions were achieved. The data was analysed by dividing the sequences into "breath groups" where the first breath group represented the first section of repetitions before a pause for breath, and the second breath group the second section of repetitions and so on. A total of five breath groups were identified for each child in this way. Three AMR times were calculated by analysing the number of syllable repetitions in the first 2 seconds of the first and second breath groups and the last 2 seconds of the fifth breath group.

The results demonstrated that the normally developing group had more syllables in the first and second breath groups than both the groups of speech impaired subjects. There was no significant difference between the three groups on the fifth breath group. There was no significant difference between the two speech impaired groups. McNutt concludes that the presence of AMR differences in children with disordered speech supports the premise that these children may have specific motor difficulties contributing to their speech difficulty.

Dworkin (1978) presented a comparison of DDK rates in a younger group of children with /s/ or /z/ articulation difficulties and a group of their normally developing peers. Each subject was recorded producing three trials of the monosyllabic repetitions /tʌ/, /dʌ/, /kʌ/ and /gʌ/, for a minimum of 3 seconds per trial. A DDK rate in repetition/3s period was calculated from the recorded data.

Dworkin (1978) noted that while there was a tendency for DDK rate to increase with age, the children with speech difficulties had significantly slower DDK rates, like those children with developmental apraxia of speech studied by Yoss and Darley (1974). In fact a recent report by Davis, Jakielski and Marquardt (1998) suggest that there are several overlapping diagnostic characteristics, including DDK rate, in a number of speech disorders, such as developmental apraxia of speech or severe phonological disorder.

In a later investigation, Dworkin and Culatta (1985) analysed the DDK rates of the monosyllables /pə/, /tə/ and /kə/ in 34 normally articulating children with a mean age of 8;1 and 24 children with disordered articulation, all of whom could produce the sequences, with a mean age of 7;7.

In the investigation by Henry (1990) cited in section 1.3.1.2 above, a lower, but still significant correlation between age and DDK performance was noted in the speech disordered children than in the normally developing children. She comments that the older disordered children may perform better on DDK tasks than the younger disordered children as a result of intervention, perhaps due to increased familiarity with the setting and the tasks A linear progression for DDK performance was plotted, and revealed that DDK scores would not necessarily increase with age at the same rate as in the normal children. This suggests that at least some speech disordered children have difficulties with motor skills. Henry points out that on the whole, the speech disordered children presented with a problem sequencing the different sounds within the nonsense sequence as opposed to the less demanding task of repeating the same sound. This can be attributed either to sequential memory difficulties or directly related to the fine motor co-ordination required to achieve different sounds within the same sequence, and a direct consequence of poorer speech motor skill.

1.3.2.3 *Consistency and accuracy of DDK performance*

The speech characteristics of children with phonological disorder leads to an expectation that such children would make some substitution errors when producing DDK sequences, and this must be taken into account in some way when considering how to calculate DDK rate. For example, a child with a severe speech impairment (as those in Henry's (1990) investigation) would be likely to have difficulty in producing some of the sounds in the DDK sequences, and this must be taken into consideration when looking at the rate results. The same comment can be made of many of the above studies, few of which mention what the investigators did when faced with a sequence that is produced inaccurately.

Some investigations have however considered the occurrence of articulatory errors, and in many cases excluded those errors from any subsequent analysis, thus depleting the data set e.g. Towne 1994, Yaruss et al 1994, Thoonen, Maassen, Wit, Gabreëls and Schreuder 1996, Thoonen, Maassen, Gabreëls and Schreuder 1999).

Towne (1994) found that the phonologically disordered children as a group demonstrated significantly slower DDK rates than the normally developing children. He notes however, in contrast to Henry (1990) above, that the DDK rate of children in his investigation did not correlate well with age in either group, while also there was little correlation of DDK rate with severity of phonological disorder. In fact, two of his phonologically disordered subjects who had the highest score on a standardised test of pronunciation presented with the poorest DDK rate performance. This inconsistency with Henry's (1990) investigation may be explained by differences in methodology (Towne's investigation involved bite-block techniques to measure articulatory compensatory ability also) and differences in defining the speech disordered populations used.

Having observed that both dyspraxic and dysarthric children have slower DDK rates than normally developing children (Yoss and Darley 1974 and Wit, Maassen, Gabreëls and Thoonen 1993, respectively), Thoonen et al (1996) set out to aid the differential diagnosis of these communication impairments using maximum performance tasks such as DDK rate. Three groups of children provided the speech data, one group of children diagnosed as exhibiting developmental apraxia of speech (DAS), one group of children diagnosed with spastic dysarthria and one group of normally speaking control children. Eleven DAS children were aged 6;3 - 7;9 years, 9 dysarthric children were aged 6;4 - 10;3 and the 11 control children aged 6;0 - 8;3. The DAS children were diagnosed based on "high rates of speech sound errors, groping of the articulators, periods of highly unintelligible speech, difficulties or inability to produce complex phonemic sequences, high incidence of context-related sound substitutions and an inconsistent speech performance" (Thoonen et al 1996:313). The children with spastic dysarthria presented with "slow speech rate, hypernasality, low and monotonous pitch, harshness of voice with strained strangled quality, and imprecise consonant production" (Thoonen et al 1996:314) and they each were quadriplegic due to infantile encephalopathy.

The monosyllables /pɑ/,/tɑ/ and /kɑ/ and the polysyllabic sequence /pɑtaka/ were recorded for each child. Bearing in mind the fact that these children may misproduce one or more of the sequences, the authors took as many trials as was necessary to produce one accurate repetition, and at least three trials were recorded for each child. DDK rate was calculated only from the accurate repetition sequences from an oscillograph display of each recording. DDK rate was calculated in syllables/s from a sequence of ten monosyllabic sequences and three polysyllabic sequences in each case. The authors also took four other measurements: they calculated the repetition ratio of the DDK rate by dividing the rate for the polysyllabic sequence by the monosyllabic sequence as an index of the motoric programming problems in speech; they calculated the variability of repetition rate, as an index of the regularity of repetitions; the number of attempts required by each speaker to produce an accurate sequence and finally an assessment of the sequencing patterns of each speaker as a further distinction between DAS and dysarthric speech patterns. (Darley, Aronson and Brown (1975) report sequencing difficulties as being more typical of apraxia rather than dysarthric speech).

The results showed that while the normally speaking children had DDK rates typical for their age when compared to a number of studies (e.g. Yoss and Darley 1974, Haselager et al 1991), those DAS children that could produce the polysyllabic sequence accurately had difficulty alternating the rapid speech movements of the polysyllabic sequence, while their monosyllabic sequences were not significantly slower than those of the control group. On the other hand, the dysarthric children had slower DDK rates on all sequences, thus providing additional clinical evidence in making a differential diagnosis.

Thoonen, et al (1999) cross-validate their earlier study in determining further the diagnostic validity of tests of maximum performance. In this study the authors compared the findings from the children in the 1996 study against other children with DAS, dysarthia, a speech disorder of unknown origin (non-specific speech disorder) and normally developing controls. The same DDK data was collected from 11 normally developing children aged 5;2 - 10;6, 9 dysarthric children aged 5;4 - 15;5, 10 DAS children aged 4;5 - 7;6 and 11 non-specific speech disordered children (encompassing children with either articulation and/or phonological difficulties) aged 4;4 - 9;11. Monosyllabic and polysyllabic DDK rates (as described in their 1996 investigation above), maximum phonation duration and maximum fricative duration were measured in each child.

The findings were interpreted in terms of their diagnostic implications. Various scoring systems were devised to indicate presence of dysarthria or dyspraxia based on the three measures. A dysathria score was based on the monosyllabic DDK rate and maximum phonation duration, where slow monosyllabic DDK rate and slow maximum phonation duration in comparison to normally developing children was seen to be indicative of dysarthria. The dyspraxia score was based on the ability to sequence the polysyllabic DDK production, how many attempts were required to produce an accurate polysyllabic sequence, polysyllabic DDK rate (of accurately produced trials only) and maximum fricative duration. Many more DAS children were unable to sequence the polysyllabic target, even with practice. Of those that could, a significantly slower rate than the control children was achieved in doing so. However there was no significant difference between the DAS children and the dysarthric children on polysyllabic DDK rate, thus the present of concomitive factors such as inability to sequence the DDK production and slow maximum fricative duration is necessary in evaluating a dyspraxia score. Each of the DAS and dysarthric children were independently evaluated by a speech and language therapist to confirm their diagnosis, with the diagnostic system matching that of the therapist for eight out of the nine dysarthric children and all of the dyspraxic children.

The findings from the non-specific speech disordered group, who presented with articulation disorder, delayed phonological acquisition, consistent deviant disorder and inconsistent deviant disorder as per Dodd's (1995) classification system (see section 1.1.1.1 above) were compared with the dysarthric and DAS children studied. Monosyllabic DDK rate was found to lie between that of the control and DAS children, maximum phonation duration was found to be similar to both the DAS and dysarthric children, while maximum fricative duration was found to be significantly shorter than the control children and significantly longer than the DAS children. These non-specific speech disordered children were more able to produce the polysyllabic sequence without making errors but they required more attempts in order to achieve an accurate production. The resultant DDK rate was significantly slower than the control children.

While the aim of this investigation is in the development of a diagnostic protocol for the differential diagnosis of DAS and dysarthria the findings are none the less interesting in understanding how children with a non-specific speech disorder (these children could also be diagnosed as phonologically disordered) perform on tests of maximum performance in relation to children with a specific motor disorder and normally developing children. These non-specific speech disordered children present with different characteristics on the range of maximum performance measures than DAS, dysarthric and normally developing children. However Thoonen et al (1999) do not describe the speech characteristics of these children. Additionally, in the control and non-specific speech disordered groups a wide age range of children was studied. As pointed out in section 1.3.1.2 above, normative studies of DDK rate children show an increase in rate associated with age, and the precise age ranges considered as crucial in the development of speech motor skill are encompassed in the groups studied. Thus, the precise details of their findings in relation to "same aged children" can be questioned. However, their investigation does indicate the value of using DDK rates in some diagnostic form.

In both Thoonen et al investigations (1996, 1999), monosyllabic DDK rate was calculated from the mean rates measured of each of the three sequences collected, and as demonstrated also in the normative data cited in section 1.3.1.2 above, alveolar-vowel sequences were faster than velar-vowel targets.

While in measuring DDK rate it must be crucial to consider mispronunciations, the nature of these mispronunciations may provide some interesting data for qualitative analysis supplementary to the DDK rate derived from accurate productions.

Williams (1996), cited in section 1.3.1.2 above, used such an approach with three single case studies of children with developmental apraxia of speech. These three children aged 8;4 years, 4;0 years and 5;0 years were each assigned an pronunciation age based on standardised assessment using the Edinburgh Articulation Test (Ingram, Anthony, Boyle and McIsaac, 1971). These children, from whom the same data set was recorded as the normally developing children in her study, performed in different ways in terms of accuracy, consistency and rate. Where the 8 year old had difficulties in terms of accuracy and consistency, the 4 year old had difficulties only in terms of accuracy and the 5 year old in terms of accuracy, consistency and rate.

These differences may be attributable to the differences in the three children's speech difficulties, particularly in terms of speech motor skill. The difficulties inherent in comparing children with a variety of different speech difficulties leads to wide interpretation difficulties.

Yaruss (1997) highlights the main problems in interpreting DDK rates, particularly in younger children. The advantages appear to be that it is relatively easy to obtain DDK rates, they are considered non-linguistic and "free from....phonological complications" (Tiffany 1980:894) and are considered to be a stable indicator of oral ability (Kent et al 1987). However, some young children do have difficulty with the task, particularly where the sounds required in the target sequence are not yet a stable feature of that child's spontaneous phonetic inventory. This raises the issue of whether or not the task is difficult because the children are unable to produce the target sounds. Thus in using relatively simple CV sequences the extent to which mispronunciations occur in young normally developing and phonologically disordered children may yield interesting findings.

Yaruss (1997) also suggests that the repetitive nature of the task can affect the accuracy and rate of production: "...it appears that rapidly repeating the same or similar segments,...can actually inhibit rapid and accurate production of target strings that have more to do with the linguistic nature of the stimuli than the oral motor skills of the speaker." He suggests that DDK rates should be assessed not only in terms of speed, but also in terms of accuracy and perhaps real words, familiar to children, may provide a more accurate assessment of maximum repetition skill. Alternatively, such real words could be collected in conjunction with altered versions such as those derived by Williams (1996).

However, while agreeing that there may be more scope for improving the target sequences or words that children could repeat, the fact remains that much of the research has preferred not to consider the accuracy and consistency of children's DDK sequences. It is possible that by looking in more depth at these CV productions (which are used extensively in current clinical practice) and considering more carefully the accuracy with which young children produce the CV sequences in relation to their connected speech ability may be a useful way of interpreting the task.

1.4 The relationship between various rate measures

Some of the investigations reviewed in the preceding sections have used more than one form of rate measure. For example, Walker et al (1992) measured articulation rate in imitated and spontaneous speech, while Haselager et al (1991) and Yaruss et al (1994) measured both articulation rate and DDK rate in the same speakers. These studies have aimed to explore the relationship between these rate measures. The following sections summarise the findings of this research.

1.4.1 Imitated and spontaneous articulation rate

In the investigation reported by Walker et al (1992) two contexts of connected speech were measured in the two age groups of children. The findings indicated an increase in articulation rate in both imitated and spontaneous connected speech contexts with age. This may indicate therefore that there is a close relationship between the articulation rate of imitated connected speech and the articulation rate of spontaneous connected speech, at least in normally developing children, in that rate of production on one measure may predict rate of production on another.

The extent to which this relationship holds for phonologically disordered children requires further investigation. In imitating an utterance, given the instruction to repeat precisely the model utterance, both normally developing and phonologically disordered children may alter their own habitual speech production patterns under the influence of the model. For example, after listening to an adult model utterance, a young child may make more of an attempt to repeat that utterance with greater accuracy than in spontaneous speech. That is, a child may give greater care and attention to accuracy in a repetition task than in spontaneous production. Such a phenomenon has been demonstrated in single word production in a single case study described by Hewlett, Gibbon and Cohen-McKenzie (1998). The child in this investigation, produced more velar targets accurately in monosyllabic single words after repeating a model than when required to name the items spontaneously from picture stimuli. Thus Walker et al's (1992) finding that articulation rate in spontaneous connected speech is faster than in imitated connected speech may possibly be attributable to the degree of care and attention the children use in producing the utterances.

The extent to which children make fewer or greater, or indeed the same, errors in an imitated task compared to a spontaneous task requires further investigation. This may provide more insight into the speech motor skills of young normally developing and phonologically disordered children.

1.4.2 Measuring articulation rate in segments/s and syllables/s

Articulation rate can be measured in a number of ways. In the studies reviewed above, articulation rate has tended to be measured in either syllables/s (hereafter referred to as syll/s) or segment/s (hereafter referred to as seg/s) or in some cases both.

In Waters (1992) investigation of phonologically disordered children, normally developing children and adults, the measure seg/s was used because it was argued the syllabic structure of young children may be reduced as a result of normal phonological development. For example, the structural simplification "process" initial cluster reduction which describes clustered targets produced as singleton consonants, would lead to less complex syllables. Waters argues that a measure of articulation rate in seg/s lends itself better to the analysis of both normally developing and phonologically disordered speech as a measure of the number of articulatory gestures that are performed over time.

Since the nature of the difficulties faced by phonologically disordered children may include the reduction of the number of segments they produce within a syllable in comparison to their normally developing peers, it can be speculated that the measure seg/s is more methodologically sound. This issue requires further investigation.

Walker et al (1992) measured both syll/s and seg/s in their study of the development of articulation rate in normally developing children, finding a strong positive relationship between the two measures. The extent to which this relationship holds in phonologically disordered children requires further investigation, particularly given the likely presence of structural simplifications in the data.

1.4.3 Articulation rate and DDK rate

In a paper by Haselager et al (1991), the authors, having recognised that both articulation rate and DDK rate increase with maturity, set out to examine the relationship between these two measurements. Four age ranges of children provided the data, with ten children in each group. The groups had mean ages of 5; 5, 7;3, 9;4 and 11;3 years. None of the children were known to have any speech or hearing difficulties.

Samples of spontaneous speech were recorded in an interview situation, followed by asking the children to produce various monosyllabic DDK sequences. These monosyllabic sequences included stops and fricatives. From oscillogram traces of the acoustic signal, articulation rate in syll/s of the spontaneous speech was calculated. The DDK rate of the first six repeated syllables in each trial was calculated also in syll/s.

The authors confirmed that both articulation rate and DDK rate increased with age. A correlation analysis found that there was a weak link between articulation rate and DDK rate, and the authors suggest that the weak correlation is due to the fact that DDK rate is, as a maximum performance task, faster than spontaneous speech. They speculate that while articulation rate increases as children mature, this may not be a reflection of the maximum speed at which they can articulate, evidenced by a DDK task.

On the other hand, in Haselager et al's (1991) investigation, one DDK rate was calculated for each child, based on an amalgamation of the rates achieved for each of the three stop CV syllables and three fricative CV syllables. As noted in the normative data for DDK rates described in section 1.3.1.2 above, there are differences in the speed with which one would expect a child to produce velar versus alveolar stops in a CV syllable, where velar CV sequences take longer to produce than alveolar CV sequences. It could be argued that similar differences could occur between stops versus fricatives. For example, fricative duration may be longer than stop duration and by amalgamating the mean DDK rates of each of these types of productions, the total effect may be compromised, in either minimising or maximising any correlation with spontaneous speech rate. (The reader is directed to Kent 1994 for a full summary of consonant durations). There is also no indication of how accurate all the children were in their DDK productions.

Yaruss et al (1994) on the other hand found a strong correlation between DDK production and articulation rate in spontaneous speech. In this investigation, the authors calculated DDK rate from ten accurate repetitions of the polysyllabic sequence /pʌtəkə/, in rep/s and syll/s, while articulation rate was calculated from conversational speech with pauses greater than 250ms excluded. The speech data was collected from normally developing children aged 3;8 - 7;6 years. In the DDK task, the children were each instructed to produce the tokens as fast as they could following a model given by the investigator. The three trials judged to be the fastest, most fluent and most accurate were selected for analysis.

The authors found that although there was a tendency for articulation rate to be faster than DDK rate this difference was not significant. A strong positive correlation was also found between DDK rate and articulation rate in these children. Both of these results are in contrast to the findings of Haselager et al (1991) above. Since DDK rate has been seen as a test of maximum performance, Yaruss et al (1994) find it quite surprising to find that the children in this investigation did not produce the DDK rates as fast as their spontaneous speech. This may be due to the calculation of DDK rate only on a polysyllabic sequence rather than on monosyllabic, bisyllabic and polysyllabic sequences.

The disparity of results investigating the relationship between these measures indicates the need for further research. Methodological and subject differences may be responsible for these discrepancies. (e.g. Haselager et al (1991) studied normally developing Dutch speakers and Yaruss et al (1994) studied normally developing and dysfluent American

English speakers.) Whether similar findings would be obtained from Scottish English speaking normally developing and phonologically disordered children is not clear.

1.5 Summary, hypothesis and specific research questions

The review of the literature above shows evidence of increased articulation rate and increased DDK rate with age in normally developing children. Evidence of reduced articulation rate and reduced DDK rate in phonologically disordered children in comparison to their normally developing peers comes from fewer investigations, each with different methodologies causing difficulties in drawing cross-study conclusions.

The evidence presented above leads to the hypothesis, tested in this investigation, that a group of phonologically disordered pre-school children will exhibit poorer speech motor skills than their normally developing peers as evidenced by measures of DDK rate and articulation rate in spontaneous and imitated connected speech data.

Supplementary to this hypothesis, a number of more specific research questions arise from the review of the related literature and are addressed in the reported investigation.

1.5.1 Articulation rate of normally developing and phonologically disordered children's imitated and spontaneous connected speech utterances

Measuring articulation rate in imitated connected speech in seg/s has provided some evidence that phonologically disordered children have slower articulation rate than their normally developing peers (Waters 1992). Whether this finding can be replicated and extended in spontaneous connected speech needs to be addressed.

Additionally, measuring articulation rate in syll/s has demonstrated a developmental progression in normally developing children in both imitated and spontaneous connected speech contexts (Walker et al 1992). A strong relationship between these two measures of articulation rate has been shown in this investigation. The extent to which articulation rate in syll/s is slower in phonologically disordered children than in normally developing children in both connected speech contexts needs to be addressed.

While a developmental progression in articulation rate in normally developing children is evident in both connected speech contexts (Walker et al 1992), this may indicate that measuring connected speech in one context is predictive of another. This needs to be addressed.

These points raise the following specific research questions:

- Do phonologically disordered pre-school children have slower articulation rate in seg/s than their normally developing peers in both imitated and spontaneous connected speech contexts ?
- Do phonologically disordered pre-school children have slower articulation rate in syll/s than their normally developing peers in both imitated and spontaneous connected speech context ?
- What is the relationship between articulation rate measures in seg/s and in syll/s in both normally developing and phonologically disordered pre-school children ?
- What is the relationship between articulation rate in the two connected speech contexts (imitated and spontaneous) in both normally developing and phonologically disordered pre-school children ?

1.5.2 DDK rate in normally developing and phonologically disordered children

There is some evidence that phonologically disordered pre-school children have slower DDK rates than their normally developing peers (Henry 1990, Towne 1994). Concerns regarding the protocols for the collection and analysis of DDK data necessitate further investigation of this finding.

Additionally Williams (1996) has shown that the productions of normally developing pre-school children's DDK sequences should be interpreted in terms of the child's own developing speech sound system and single word imitations pre assessing DDK rate.

These points raise the following specific research questions:

- Are the accurate realisations of DDK sequences produced by phonologically disordered children slower than the accurate realisations of same aged normally developing children?
- Can further advances using an error analysis approach to DDK productions further the knowledge of the possible deficits underling phonological disability in young children?

1.5.3 The relationship between articulation rate and DDK rate

There is conflicting evidence of a relationship between articulation rate and DDK rate (Haselager et al 1991, Yaruss et al (1994). What is the nature of any relationship between these two measures in both normally developing and phonologically disordered pre-school children?

1.5.4 Identifying phonologically disordered children with an underlying speech motor skills deficit

Can measures of articulation rate and DDK rate, together with further analysis of DDK performance assist in the identification of those children with phonological disability who have an underlying deficit in speech motor skills?

1.5.5 Methodological issues in measuring speech motor skills

In reviewing the literature above it has become apparent that there are a number of methodological issues surrounding measuring speech motor skills using rate measurements in normally developing and phonologically disordered pre-school children. These issues are considered in the following chapter.

Chapter Two Methodological Issues

The reported investigation aims to test the hypothesis that phonologically disordered pre-school children will exhibit poorer speech motor skills than their normally developing peers, as evidenced by measures of DDK rate and articulation rate in spontaneous and imitated connected speech data. In designing an experiment to test this hypothesis, and more specifically to address the additional research questions which arise from the literature review, a number of methodological factors have to be taken into consideration.

This chapter explores these methodological issues. Section 2.1 considers experimental design in relation to connected speech data, while in section 2.2 experimental design in relation to DDK data is explored. Section 2.3 considers methodological issues in collecting these types of data from normally developing and phonologically disordered pre-school children.

2.1 Experimental design in relation to connected speech data

Investigations cited in chapter one employ several different methods of recording and analysis. In the following sections a number of issues are explored, namely the connected speech context, methods used to gather connected speech data from young children and methods used to measure the rate of production of connected speech.

2.1.1 The context of connected speech : spontaneous versus imitated

There are both advantages and disadvantages to recording spontaneous and imitated connected speech samples. Spontaneous connected speech provides data that is a reflection of natural ability, while imitated connected speech data automatically imposes utterances on the child that may not be completely natural to him or her. However, it is very difficult to make comparisons between children's spontaneous connected speech, where these utterances may be very diverse.

Amster (1984) recorded a sample of conversational speech using toys and books as stimuli for spontaneous production.

Waters (1992) collected repeated trials of an imitated connected speech utterance: "two naughty boys are playing in the..." with three alternate final words (all with the same initial consonant) to provide motivation and variation for the children. Each of the three alternative utterances were pre-recorded and a task designed where the subjects had to listen to the model utterance and repeat it back to the investigator.

Walker et al (1992) on the other hand collected both imitated and spontaneous connected speech utterances. Spontaneous speech was gathered using a story telling task where each child was asked to tell the story "Goldilocks and the Three Bears" using picture stimuli. For their imitated utterances two pre-determined utterances: "I took a toy" and "I saw a cow and gave him some hay" were gathered from each child. In addition to this, two utterances selected from each child's spontaneous connected speech were also presented to the children for imitation.

Eliciting spontaneous connected speech from subjects can cause difficulty in comparing various subjects within one study, where the range of utterances may be diverse in terms of the context. However, Walker et al (1992) appear to have overcome this by asking children to tell a story, which it was assumed would have been familiar to them.

Whether the connected speech sample is imitated or spontaneous in nature, it is crucial that any investigation considers carefully what is understood by the definition "utterance". As pointed out in chapter one, calculation of rate of connected speech production can be affected by a number of variables, and in terms of "utterances", the length of the connected speech sample is of importance.

2.1.1.1 *Utterance length*

Care must be taken when defining an "utterance" as this may range from single syllable answers to lengthy monologues. Previous studies refer to both "utterances" and "runs" of connected speech. For example, Miller, Grosjean and Lomanto (1984) define a "run" of speech as a stretch of speech that contains no pauses, with a pause defined as a silent interval of 250ms or greater.

Additionally, there is evidence that the length of an utterance has a direct effect on speech rate. Haselager et al (1991) and Ryan (1992) for example have shown that the longer the utterance is (in syllables), the faster the speech rate, and there is therefore a need to control for this phenomenon when comparing the spontaneous and imitated connected speech of children. Where the number of syllables is specified in an imitated utterance, then the criteria for analysis of the spontaneous utterances should be set within the same limits, to allow comparison of rates in the two types of speech materials. For example, where the imitated utterance is 6 syllables in duration, those spontaneous utterances which are as close as possible in length should be selected for comparison.

2.1.1.2 *Rate of presentation of model for imitation*

Regarding rate of presentation of a modelled utterance for imitation, there are differences in methodologies reported in the literature that may have bearing on the findings reported. Where Waters (1992) presented the modelled utterances at an adult rate of production, (kept constant for all subjects) Walker et al (1992) presented their modelled utterances at what was considered to be a child-like rate of production. Bonvillian, Raeburn and Horan (1979) suggest that children make fewer errors when asked to imitate an utterance presented at a rate similar to their own. However, young children may similarly reduce their own rate in response to what is perceived as an artificially slow adult presentation and the instruction to imitate precisely what they hear.

Were the modelled utterances presented to the children at a normal adult rate (as in Waters 1992) this would allow for comparisons with the child's spontaneous rate in terms of both speed and accuracy. This is particularly the case when investigating disordered speech.

It is however, more crucial having decided on presentation rate to be consistent with every child recorded. This can be controlled for by presenting each child with the same pre-recorded stimulus for imitation at each data collection session.

2.1.2 Collecting connected speech data from young children

Collecting connected speech from young children that is of suitable quality for acoustic analysis requires a great deal of planning. High quality tape recording must be carried out in an appropriate environment, preferably a sound proof recording studio. This environment is likely to be unfamiliar to a young child. It is therefore crucial that any studio used for this purpose be set up to allow a child's parent/guardian to sit in on the recording with the minimum of interference.

Ideally a young child should not be expected to interact freely with an unfamiliar adult in such an environment. For this reason, any research requiring interaction with pre-school children should involve at least one visit prior to the recording to allow the child to become familiar with the researcher and/or the environment.

Stimuli used to collect speech data from young children must be appropriate to their interests and attention. Those studies reviewed in chapter one that collected spontaneous connected speech data used a variety of techniques to do so, such as a story telling task (e.g. Walker et al 1992) or by using books and toys as stimuli (e.g. Amster 1984).

Where a story telling task is used it is assumed that the child is already familiar with the story and thus able to retell it. However, this assumption may be incorrect, and the child may need to hear the story before being comfortable with retelling it. Where an investigator presents a story for retelling, there is the danger that the child may imitate precisely the adult utterances and not produce natural spontaneous speech. Additionally, the style of presentation to a number of different children must be controlled.

2.1.3 Measuring the rate of production of connected speech

As pointed out in chapter one, section 1.4.2, articulation rate can be calculated in syll/s or in seg/s from the spectrogram of the utterance. Haselager et al (1991) and Walker et al (1992) calculated articulation rate from only those utterances that were free of pauses greater than 250ms in duration.

As noted in section 1.3.1 previously, the time taken to produce an utterance can be described as either speech rate or articulation rate. Speech rate, sometimes referred to as speaking rate, can be defined as the rate of speech of a whole speaking turn. This speaking turn may include any number of pauses that are associated both with breathing, lexical processing and the silent interval associated with organising the gestures for speech production. Articulation rate on the other hand refers only to the rate with which a given utterance is produced, excluding silent intervals that are not associated with gestural co-ordination (Laver 1994). Most researchers define pauses as periods of silent interval greater than 250ms in duration. Of the studies reviewed in chapter one, where pauses have been excluded from the analysis this criterion has been used in all but one investigation. Campbell and Dolloghan (1995) defined pauses as periods of silent interval greater than 100ms rather than the standard 250ms. They justify this in terms of interpreting pauses as representative of the cognitive and linguistic factors in speech production, and that while the longer duration may reflect such processing in normally speaking subjects the same may not necessarily hold for children with TBI.

However, for the purposes of investigating the speech motor skills of children who have a phonological disability and no evidence of cognitive or linguistic difficulties, the upper limit can be regarded as appropriate. Thus, articulation rate can be calculated from samples of connected speech by deducting the sum of the pauses greater than 250ms from the total utterance duration. This figure represents the total amount of time the articulators are in use and can be identified as "total articulating time" from which a calculation of articulation rate can be made.

To demonstrate this, figure 2.1 below shows two waveforms of a normally developing 4 year old child's spontaneous speech. The top waveform is of the utterance "he's going to wake him up" [hiz goɪŋ tə wek hɪm ʌp], with a pause produced between "he's" and "going". The bottom waveform is of the utterance "but first he's going be cheeky" [bʌʔ fɪrs hiz goɪŋ bi tʃiki], where no pauses are evident. From these waveforms a number of measurements can be taken. To derive a speech rate in syll/s, the number of syllables produced in the utterance must be divided by the total utterance duration. This sum is then multiplied by 1000/1 to give a rate in syll/s. The speech rate of the first utterance, where 7 syllables were produced in 2456ms has been calculated as 2.85 syll/s, while for the second utterance, where 8 syllables were produced in 2078ms has been calculated as 3.85 syll/s. However when calculating articulation rate, the pause of 824ms is subtracted. Thus, it took 1632ms to produce this 7 syllable utterance, where this time represents the total time the articulators were in use. An articulation rate of 4.29 syll/s can be calculated from this.

The conclusion that can be drawn from this therefore is that pauses affect the rate of production of an utterance, and where the time taken to produce a series of co-ordinated gestures is being investigated, these pauses should be excluded from the analysis.

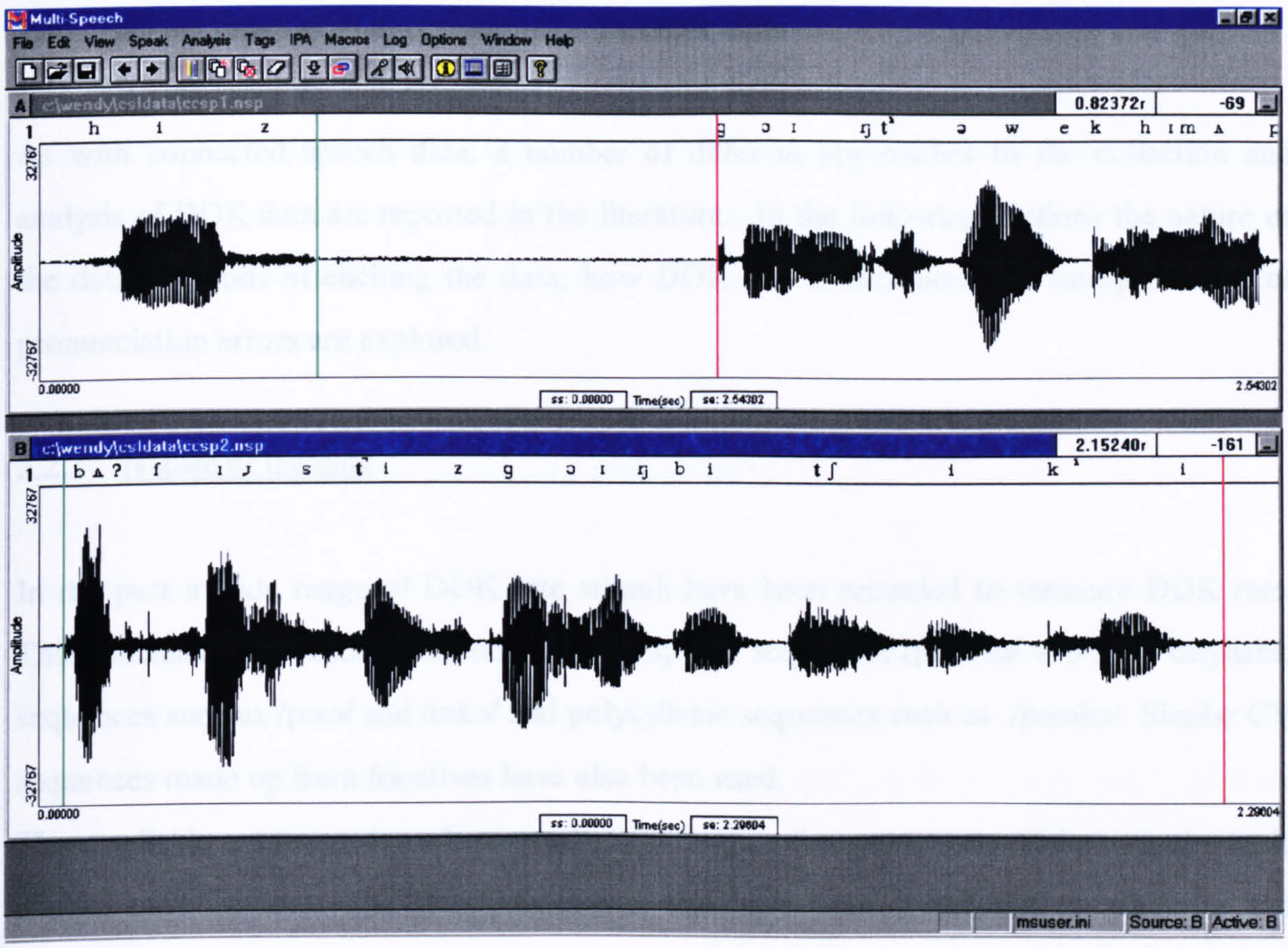

Figure 2.1 Waveforms of a normally developing child's spontaneous utterances (a) "he's going to wake him up" and (b) "but first he's going be cheeky". In the top waveform the markers indicate the pause between the first two words of the utterance, while the markers in the bottom waveform indicate the onset (in green) and offset (in red) of the whole utterance.

When investigating disordered children's connected speech utterances it is crucial to consider the habitual speech patterns of these children in their spontaneous and imitated utterances. Where both spontaneous and imitated samples of speech data are collected, the sample contains examples of the child's habitual productions that can be compared against any error patterns produced in an imitated context. This is particularly useful given the findings reported by Hewlett et al (1998) described in chapter one, section 1.4.1 where at the single word level, a phonologically disordered child was able to imitate velar targets with greater accuracy than in spontaneous production.

Analysis of pronunciation patterns may follow the descriptive patterns of process analysis proposed by linguists in relation to the substitution patterns evident in child speech. This follows Stampe (1969) who described the course of normal phonological development as a rule system, where the child applies a specific rule to the pronunciation of a sound.

2.2 Experimental design in relation to DDK data

As with connected speech data, a number of different approaches to the collection and analysis of DDK data are reported in the literature. In the following sections the nature of the data, methods of eliciting the data, how DDK rate is measured and interpretations of pronunciation errors are explored.

2.2.1 <u>Nature of the data</u>

In the past a wide range of DDK rate stimuli have been recorded to measure DDK rate. These include the traditional monosyllabic stop CV sequences /pə/, /tə/ and /kə/, bisyllabic sequences such as /pətə/ and /təkə/ and polysyllabic sequences such as /pətəkə/. Similar CV sequences made up from fricatives have also been used.

These syllable sequences have been used to investigate the movements of the articulators in bilabial, alveolar and velar stop production, and have been considered an adequate and appropriate technique to measure these movements in what is described as a rapid, alternating task involving the movement of the articulators. Where some studies have used real word alternatives such as "pattycake" or "buttercup" (Robbins and Klee 1987 and Canning and Rose 1974, respectively) there is the danger that the task then involves some element of lexical processing, imposing on the speaker the set(s) of rules he or she may apply to producing that word.

Yaruss (1997) however suggests that despite the abstract nature of repeating these syllabic sequences, there are some constraints imposed by the task where repeating the same phoneme over and over again can induce articulatory error in adult speakers. He does however comment that although this phenomenon has been shown in adults it is currently not clear whether children would present with similar errors. Although both Williams (1996) and Yaruss (1997) advocate the use of syllable sequences that have been derived from real words, and the use of real words in fast repetition, this is a relatively new approach to the administration of DDK tasks, and requires further research before it could be adopted in place of the more well-established methods.

However, the normative rates for production of the various monosyllabic, bisyllabic and polysyllabic CV sequences reported in the literature vary between studies. Where for example the mean DDK rate for [pʌ] in the 5;0 - 5;6 age range reported by Robbins and

Klee (1987) is 4.76 repetitions/s (hereafter referred to as rep/s), St Louis and Ruscello (1987) report a rate of 3.47 rep/s for the same syllable in the same age range.

In the light of this discrepancy, which must be attributable to differences in methodological design, further research on the traditional CV syllabic sequences is required, taking into consideration perhaps the methods used to elicit, record, analyse and interpret the DDK data.

2.2.2 Methods used to elicit DDK data from children

The discrepancies in the normative data highlighted above can be attributed to methodological differences in the procedures used for the collection of DDK rate data. Two specific areas of concern can be identified, firstly difficulties concerned with eliciting the data, and secondly issues concerned with recording the data for analysis. When eliciting data from young children it is crucial that the instructions given do not detract from the task itself. As pointed out by Kent et al (1987) in any measures of maximum performance, the instructions given to the subject can affect the data. Table 2.1 below shows the precise instructions given to subjects in each of the published normative studies of DDK rate.

In some of the studies, the instructions for eliciting the data are given together with instructions for evaluating DDK rate from the elicited data, and it is apparent from the excerpts in the table above that the variation in instruction is related to the method of evaluating the rate of production of the DDK sequence. Methods used to measure DDK rate are discussed further in section 2.2.3 below.

However, when collecting DDK sequences from adult speakers these instructions may be relatively simple to follow, it has been observed that where a young child is instructed to repeat a CV syllable for as long and as fast as they can, it is often the case that young children increase volume in place of or in addition to increasing speed (Williams and Stackhouse 1987, 1998, Cohen, Waters and Hewlett 1998). Thus, the method used to elicit these repetition sequences in young children must be designed with this in mind, to ensure the children understand what is required, concentrate on the task and in doing so produce a series of DDK repetition sequences as fast as they can.

Study	Instructions to subjects
Fletcher (1972:764)	"I want you to say some sounds for me. They aren't words, just sounds. I'll show you how to make it first, then you can say it with me. Then you try it yourself as fast as you can, The first sound is ... [for example, /pʌ, pʌ, pʌ, ... pʌ/]. Now try it with me - [first practice trial of approximately three seconds] OK, that's the way. Now try it by yourself, as fast as you can . . . [second practice trial of approximately three seconds]. Good...fine. Now I want you to do it once more. This time it has to be a long one. I'll tell you when to start,. Don't stop until I tell you. Ready. Start. [Repetitions counted in this third trial]. The next sound is ________"
Canning and Rose (1974:48)	"The subject first imitated one of the consonants in isolation (usually /t/). The tester then demonstrated a series of rapid repetitions of this individual consonant and the subject practised for a short time. He was then reminded to do the task quickly and his efforts were recorded on tape (speed 3¾)."
Oliver <u>et al</u> (1985)	The protocol in the Frenchay Dysarthria Assessment (Enderby 1983) was used. In this, the investigator "asks the patient to say each of three sequences ["pa pa", "oo ee" and "ka la"] ten times as quickly as possible." (1983:21) The investigator demonstrates ten units in five seconds and the second attempt is scored on a rating scale.
Robbins and Klee (1987:272)	"The mean number of repetitions per second, produced over a 3-s interval were calculated for each of the three monosyllabic forms (/pʌ/, /tʌ/, and /kʌ/) and each of two polysyllabic forms (/pətəkək/ and *patticake*). Subjects were instructed to repeat each of these forms as quickly as possible during the 3-s interval"
St Louis and Ruscello (1987:6/7)	"It is recommended that the examiner use the four fingers of one hand to aid in counting each movement because the required totals are all multiples of 4. For example, to determine the time required for 16 /pʌ/ repetitions, first model at least 10 rapid repetitions for the client. Next, ask the client to practice briefly, reinstructing him or her if necessary. Then tell the client to start repeating the syllable as fast as possible when told to begin and to continue until told to stop."

Table 2.1 Instructions to subject used to elicit DDK sequences in normative studies of DDK rate

When calculating DDK rate using the time-by-count technique, the instruction given is to repeat a specific number of syllables as fast as possible. With young children, this may not be possible where they may not yet be able to count up to the required number. Thus, it is important to consider the task used to elicit the data to avoid young children increasing volume or concentrating on a different cognitive task in counting their productions. One solution to this latter issue is to analyse DDK rate in either syll/s or rep/s from a tape recorded sample, ideally using acoustic analysis techniques to determine the precise beginning and end points of the repetition sequence. This would allow the experimenter to concentrate on encouraging continued production by the child and not on counting the syllables produced.

In the acoustic analysis of any speech sample, high quality tape recording of the sample is required. This requirement is generally met in those papers measuring articulation rate, but not in all studies involving the collection of DDK rate data, where in some cases rate is calculated from the tape recording and a stop watch, and not with the assistance of acoustic analysis. Even the most precise stopwatch may not be able to record the duration of a string of productions produced by a young child, particularly where a young child may not maintain a string of repetitions on one breath for a long time. The current availability of instrumental analysis procedures makes it increasingly unlikely that non-instrumental analysis alone can be regarded as acceptable.

2.2.3 Measuring DDK rate

There are a number of different methods used to calculate DDK rate. The count-by-time and time-by-count approaches are said to yield the same information (Fletcher 1972), both giving DDK rate in rep/s. In some of the literature however, subjects have been asked to produce different numbers of sequences. Where Fletcher measures the amount of time taken to produce 20 repetitions of /tə/, Canning and Rose measure the amount of time to taken to produce 10 repetitions. Oliver et al (1985) evaluate rate over five repetitions while Robbins and Klee (1987) on the other hand asked each subject to repeat the syllables for 3 seconds. St Louis and Ruscello (1987) convert the time taken to produce 16 monosyllabic repetitions into a rate in rep/s. Thus, while it is generally accepted that DDK rate does not change over the course of a sequence, regardless of its length (Kent et al 1987), these differences may account for the discrepancy in reported normative DDK rate data across various studies for children of the same age.

It could be suggested therefore, that in order to simplify analysis, DDK rate could be calculated from a string of repetitions, as long as each subject is able to produce, as in calculations of articulation rate. Tiffany (1980) calculated the DDK rate of an utterance from the beginning of the second syllable to the end of the last syllable. However, in temporal measurements from an acoustic signal, there may be periods of closure before the release of a stop consonant, and care must be taken in defining the precise point at which the syllable starts.

Using acoustic analysis software to analyse DDK rate, it is possible to examine carefully the extent to which a speaker manages to produce the syllable accurately, producing both the C and the V segments of the syllable. Thus a perceptual based analysis of a DDK repetition can be supplemented from the acoustic display in defining whether or not a target syllable has been produced accurately.

Regardless of technique used to measure DDK rate, the decision has to be made whether or not to measure rate from all productions or accurately produced trials only. Perceptual based transcription, supplemented by acoustic analysis, of the string of repetitions can be used to determine which syllables have been produced accurately.

2.2.4 Interpretation of pronunciation errors

It has been suggested previously that mispronunciations or sequencing errors must be taken into consideration when calculating the DDK rates of an individual speaker. The analysis of accuracy and consistency of DDK performance may provide useful information about the types of errors normally developing children and children with various forms of speech impairment may make in producing the DDK sequences.

For example, where a child makes an error in producing a DDK sequence that is also reflected in spontaneous speech output, this could be interpreted as a difficulty at the phonological level. Where the same child makes an error that is not reflected in spontaneous speech, then it is conceivable that this type of error is not at the phonological level, but perhaps an effect of oral motor skill, or lack of it, (i.e. an error "forced" by the maximum performance condition)

Additionally, errors in sequencing a DDK production may reflect the increased demands of the task in the child who cannot co-ordinate rapid movements from one place of articulation to the other as a result of poor speech motor skills.

2.3 Experimental design in relation to normally developing and phonologically disordered pre-school children

Investigations of the development of articulation rate and DDK rate have used a wide age range of children. When considering the development of phonological and articulatory skill, the age at which one expects a child to have acquired fully stable and adult-like phonological and articulatory skills is approximately 7 years, based on perceptually based assessment (Grunwell 1981, Kent 1994).

Additionally, where a child with speech disability has enrolled in a course of therapeutic intervention, any data recorded may be unrepresentative of that child's spontaneous speech abilities prior to therapy (Henry 1990). Thus, it would be considered ideal to record the speech from disordered children before they have been enrolled in a course of therapy. Additionally, when recording speech from young children it is important to consider when they will be old enough to participate, often the age at which they are old enough to receive speech and language therapy.

Most phonologically disordered children will have been enrolled in such a course of therapy at least before entering school, thus by selecting an age range representing children within their pre-school year, the effect of intervention can to some extent be controlled. This age is in the range of 3;5 - 5;0 years.

2.4 Summary

The preceding sections have raised a number of methodological issues that require addressing when investigating the articulation rate and DDK rate of young children's speech. Articulation rate can be measured from imitated or spontaneous connected speech, while DDK rate evaluated on repetitions of various strings of CV syllables.

In devising the method used in the reported investigation, all the issues discussed above were taken into consideration. The method devised is reported in the following chapter.

Chapter Three Method

The following chapter describes the method used in the reported investigation.

3.1 Subjects

A total of 28 child subjects between the ages of 3;08 and 5;03 were recruited to the full investigation.

3.1.1 Normally developing subjects (Group N)

The normally developing children (hereafter referred to as N children) were recruited from both local play groups and from posters distributed throughout Queen Margaret College Corstorphine Campus. Letters, consent forms and short questionnaires (see Appendix 1) were sent to various playgroups, and local state nurseries. These letters were then distributed to those parents of children within the age range specified for the investigation. For those parents/guardians who responded to a poster, a similar letter was sent directly to them. Parents were invited to return these consent forms and questionnaires using the stamped addressed envelope supplied. The first fourteen children who satisfied the inclusion criteria following assessment of suitability (see section 3.1.4 and table 3.1) were included in the investigation.

3.1.2 Phonologically disordered subjects (Group P)

The phonologically disordered children (hereafter referred to as P children) were recruited through speech and language therapists working in the communities of Edinburgh, Fife and surrounding areas. Local therapists were approached in the first instance through their staff teams. A presentation on the purpose of the investigation was made to each of these staff teams. A follow up letter was sent to each team manager, enclosing letters, consent forms and questionnaires for parents, (see Appendix 2) for return to the investigator. Local therapists were asked to contact the investigator by telephone to advise of suitable candidates. This ensured that these subjects would not experience any delay in enrolment for a course of therapy, and that data collection could take place immediately following initial referral for speech and language therapy assessment, and immediately prior to intervention. The first fourteen children who satisfied the inclusion criteria following assessment of suitability (see section 3.1.4 and table 3.1) were included in the investigation. The pattern of service delivery was such that it proved difficult to recruit subjects who had not received any therapeutic intervention prior to inclusion in the investigation. Consequently, managers were subsequently informed that any child with a phonological difficulty would be considered for recruitment to the study, and those children who had already been enrolled for a course of therapy could be included in the study. Of the fourteen children recruited to the investigation, seven children were already enrolled in a course of therapy.

3.1.3 Ethical Approval

3.1.3.1 *Normally developing subjects*

Ethical approval for the recruitment of children from local playgroups was granted by Queen Margaret College's Ethics Sub-Committee and the Education Department of the City of Edinburgh District Council.

3.1.3.2 *Phonologically disordered subjects*

Ethical approval for the recruitment of phonologically disordered subjects who attended Community Trust Clinics for assessment and treatment was granted by the Paediatrics and Reproductive Medicine Research Ethics Sub-committee of Lothian Health and the Fife Local Research Ethics Committee of Fife Health Board.

3.1.4 Assessment for suitability

All children were assessed for inclusion in the study using the short questionnaire (see Appendices 1 and 2) completed by the parent/guardian and standardised speech and language assessments. Inclusion criteria for the phonologically disordered group was based on the definitions for phonological disability defined by Grunwell (1981) and described in chapter one, section 1.1.1. The children studied had specific phonological difficulties in the context of otherwise age appropriate language abilities. Standardised speech and language assessments were administered in the child's home. Only one child had recently been assessed in their local clinic using these standardised speech and language assessments. Copies of the results of these assessments for this child were obtained rather than further assessment being carried out, since reassessment within 6 months of initial assessment invalidates the results. Due to the standardised nature of these assessments, such testing by a qualified person (i.e. their local speech and language therapist) was deemed reliable.

Responses to the short questionnaire regarding the child's speech, language and hearing development were followed up during the home visit. Where any parent had expressed concern about their child's hearing ability, information about their performance during hearing screening assessments was sought. Within the Health Board areas from which the children were recruited, it is routine that children who fail two hearing screening tests are referred for full audiological consultation. Any child so referred did not satisfy the inclusion criteria for the investigation and was thus excluded.

	Indicator	Group N	Group P
Age		**3;05 - 4;11**	**3;05 - 4;11**
Hearing	parental questionnaire	normal	normal
Language spoken in home	parental questionnaire	monolingual - English only	monolingual - English only
Verbal Comprehension	Reynell Developmental Language Scales - Comprehension (Reynell 1985)	not more than one standard deviation below the mean	not more than one standard deviation below the mean
Expressive Language	Renfrew Action Picture Test (Renfrew 1988)	age equivalent scores not more than 6 months below C.A. in both information and grammar scores	age equivalent scores not more than 6 months below C.A. in both information and grammar scores
Acquisition of speech sound system	Edinburgh Articulation Test (Ingram et al 1971)	standard score > 100	standard score < 85 (i.e. one standard deviation below the mean) (the test suggests that those children with a score of <85 may require a course of therapy)

Table 3.1 List of criteria for inclusion in the investigation

3.1.5 Summary

Table 3.2 below shows all those children who having satisfied the inclusion criteria proceeded to speech recording.

Normally developing children (Group N)			Phonologically disordered children (Group P)		
Code number	Sex	Age	Code number	Sex	Age
N1	F	3;10	P1	F	4;0
N2	M	4;2	P2	M	3;9
N3	F	4;6	P3	M	4;2
N4	M	4;3	P4	M	4;6
N5	M	4;5	P5	M	3;11
N6	M	4;6	P6	M	4;9
N7	M	4;0	P7	F	3;10
N8	M	4;7	P8	M	3.9
N9	M	4;5	P9	M	5;3
N10	M	4;10	P10	M	5;1
N11	F	4;0	P11	M	5;1
N12	F	4;0	P12	F	4;6
N13	M	4;4	P13	M	3;8
N14	M	4;11	P14	F	3;9
Total number of children		**14**	**Total number of children**		**14**
Total number of boys		**10**	**Total number of boys**		**10**
Total number of girls		**4**	**Total number of girls**		**4**
Age range		**3;10 - 4;11**	**Age range**		**3;8 - 5;3**
Mean Age		**4;4**	**Mean Age**		**4;3**

Table 3.2 Table showing the age and sex of all the subjects at the time of data collection

3.2 Speech data, materials used in data collection and data collection procedures

Eliciting data from young children can be difficult, and for this reason care was taken in designing the elicitation tasks. Difficulties can be encountered in ensuring the task is interesting and simulating enough for these children. In the light of the methodological issues raised in chapter two, the procedure used in this investigation is described in detail. Four tasks were designed to elicit the speech data from each subject. The data elicited were single word utterances, spontaneous connected speech, imitated connected speech and DDK syllable repetitions.

3.2.1 Single word speech data

Single word data consisted of 44 words in the Metaphon Resource Pack Screening Assessment (Dean, Howell, Hill and Waters 1990). Each word is represented by a picture, supplied with the Resource Pack, and the data was collected using confrontation naming of these picture materials.

The screening assessment is designed to provide suitable data for a brief analysis of the child's phonological system in single word productions.

3.2.2 Spontaneous connected speech data

A sample of spontaneous connected speech was collected in a story telling task. A short video, about 5 minutes in duration, of a "Thomas the Tank Engine" cartoon was played to each child. During a second playback the sound was turned off and the child invited to tell the story along with the cartoon.

The context of the cartoon provided the investigator with some level of predictability of spontaneous utterances across all subjects. This is particularly useful when dealing with the speech of unfamiliar P children.

3.2.3 Imitated connected speech data

Imitated connected speech data was collected using computer graphics with multi-media audio attachments. Eight pictures were drawn and scanned to provide computer graphics illustrating four stimulus sentences. Two of these pictures depicted two boys picking bananas, two pictures of the same boys picking apples, two pictures of the boys picking oranges and two pictures of the boys picking flowers.

These graphics were loaded into Powerpoint™ software. Pre-recorded multi-media attachments for each picture were loaded onto the PC. These attachments consisted of the investigator saying a sentence corresponding to the picture on the screen. These sentences were :

two naughty boys are picking some bananas
two naughty boys are picking some apples
two naughty boys are picking some oranges
two naughty boys are picking some flowers

Two copies of each picture were displayed on the computer screen, giving a total of eight small pictures visible at the same time. Each child was instructed to look at each of the pictures, and invited to "listen to the story about each one". After the child had seen each of the pictures once, and listened to its story, all the pictures were hidden away by the computer, with the screen displaying eight empty frames where the pictures had once been. The child was then instructed to select any one of these frames to find a hidden picture and listen to its story. Delayed imitation of the carrier phrase was achieved by asking the child to tell the story "that the lady on the computer told you". The child was asked to find each picture once, and thus eight utterances of the experimental phrase "two naughty boys are picking....." were recorded for each child.

3.2.4 DDK data

Each child was introduced to the syllable sequences used to elicit the DDK data, by using a toy train set. It was explained to each child that in order for the train to move, the driver needed to hear a "special sound said again and again, clearly but as fast as you can because the train is running late today". This special sound changed when the engine pulled different coloured carriages. By assigning a specific sound to each coloured carriage, it was possible to string sounds together. For example, the green carriage was associated with the syllable /pə/, the red carriage was associated with the syllable /tə/ and the yellow carriage was associated with the syllable /kə/. Thus, by joining the carriages together, various syllable sequences were achieved, including the bisyllabic sequence /pətə/ and the polysyllabic sequence /pətəkə/, as shown in table 3.3 below.

target syllable(s)	train carriage(s)
/pə/	green
/tə/	red
/kə/	yellow
/pətə/	green and red
/pətəkə/	green, red and yellow

Table 3.3 Train carriages used to achieve target syllables and syllable sequences

As the investigator "pulled" the train, the child produced the sequence. This was repeated five times, giving five trials for each syllable sequence for each child. To enhance the "game" atmosphere, the child first "pulled" the train for the investigator to make the sound sequences, thus giving a clear model to each child of the required sequence.

3.2.5 Recording procedures and equipment

The four speech samples were obtained from all but one subject in two recording sessions.[2] In the first session single word speech data and spontaneous connected speech data were collected. Imitated connected speech data and DDK syllable repetition data were collected during the second session.

Each session lasted between 30-45 minutes per child.

Before each task was administered, each child was encouraged to take part in free play with the investigator in order to gain confidence with his or her surroundings. This also provided the opportunity to optimise recording levels.

All recording took place in a recording booth in the Speech Research Laboratory of the Department of Speech and Language Sciences in Queen Margaret College. Parents were invited to sit in on the recording at all times.

All speech data were recorded onto digital tape using a Sony Digital Audio Tape Recorder, DTC 60ES. The children each wore the same Audio Technica AT803B lapel microphone to provide a constant distance for recording during each activity.

3.3 Preliminary data analysis

3.3.1 Perceptual / auditory based analysis

3.3.1.1 *Single word data*

Broad phonetic transcriptions were made of the single word responses (see appendix 6). The transcribed utterances were used to make a phonological analysis of the child's speech sound system. The most useful technique used to describe a child's phonological system is that of process analysis, following Stampe (1969). A number of procedures used for phonological assessment in disordered speech describe the child's output using process analysis, including Grunwell (1985) and Dean et al (1990). Since the data was collected using Dean et al's (1990) framework, the processes described by this framework were used. From this process analysis, the occurrence rate of each process was converted into a percentage occurrence for each child. Those phonological processes that occurred in each child's speech sound system were noted for word initial, intervocalic and word final position.

3.3.1.2 *Spontaneous connected speech data*

Full orthographic transcription of the speech sample provided a number of utterances that would be used for further analysis. An utterance was defined as "one speech turn". Utterances that were between 6 and 9 syllables in length were selected for analysis, in order to maintain similar lengths of utterance for each child and comparability with the imitated connected speech data (see section 3.3.1.3 below). The first eight such utterances were

[2] Subject N1 attended a third recording session due to recording equipment failure in the second session.

selected from each child's sample. Six children (N12, P8, P9, P10, P11 and P12) did not produce eight utterances equal to or greater than 6 syllables in length. N12 produced five, P8 produced four, P9 produced seven, P10 produced three, P11 produced five and P12 produced six. As a result of some children producing fewer syllables that were between 6 and 9 syllables in length, it was not possible to analyse a defined experimental portion for each of the spontaneous utterances. Thus, the spontaneous utterances represented the complete utterance produced without elimination of a final word or syllable since this would have reduced the overall utterance length, while the experimental phrase from the imitated connected speech sample which consisted of part of a carrier phrase.

Broad phonetic transcriptions of these utterances were made to assist in the acoustic analysis (see appendix 8). From this transcription, a full analysis of the phonological processes present in each child's spontaneous connected speech output was also made using the same process analysis as for the single word data. A percentage occurrence for each of these processes in the spontaneous connected speech sample was evaluated for each child. As with any samples of data, the data set may be limited in terms of providing a complete description of all phonological processes present in a child's speech. It is only possible to comment on a child's phonological abilities based on the data recorded.

3.3.1.3 *Imitated connected speech data*

Broad phonetic transcription of all eight tokens of the utterance "two naughty boys are picking" were made to assist in further acoustic analysis (see appendix 7).

From this transcription, an analysis of the phonological processes present in each child's imitated connected speech output was also made, using the same process analysis as for the single word and spontaneous connected speech data. The target utterance did not however contain a full range of speech sounds to probe for all possible simplification processes. A percentage occurrence for each of the processes evident from the sample was evaluated for each child.

3.3.1.4 *DDK sequences*

Broad phonetic transcriptions of each trial of the DDK syllable repetition task were made to assist in further acoustic analysis. Occurrence of errors were noted for each child. These errors were further analysed as being either predictable in the context of the child's single and connected speech data or they were not predictable.

3.3.2 Spectrographic analysis

Both Kay Computerised Speech Laboratory™ (CSL) software and Kay Multispeech™ software were used for all spectrographic analyses. Each digitised utterance was loaded into the system which provides various displays of the speech signal. A sampling rate of 20,480Hz was selected. Both the CSL and Multispeech systems have a number of cursors which can be placed at strategic points on the spectrogram to assist with duration measurements.

3.3.2.1 *Utterance length and utterance duration in the imitated and spontaneous connected speech samples*

The total number of syllables was counted in each spontaneous and each imitated utterance. A mean number of syllables per utterance was calculated for each child.

The duration of each of the utterances was measured from the onset of energy associated with the first segment of the utterance to the offset of the energy associated with the final segment of the utterance. In the imitated connected speech samples, the duration was calculated from the onset of the release of closure in the stop consonant /t/ of "two" to the offset of the /ŋ/ of "picking". A mean utterance duration was calculated for each speech sample for each child.

In both the spontaneous and imitated connected speech data, all pauses were noted, with their respective durations. Pauses greater than 250ms were identified, the durations measured and subtracted from the utterance duration to give a total articulating time.

The results of this analysis allow for both a comparison to be made between the two groups of children and a comparison between the two connected speech samples in terms of utterance length and utterance duration.

3.3.2.2 *Articulation rate for spontaneous and imitated connected speech data*

Having calculated the total duration of each spontaneous and imitated utterance, the duration of any pauses greater than 250ms and the total number of syllables, the total number of segments was also calculated. The phonetic transcription was used to assist in the identification of perceptually distinct syllables and segments. An example of this segmentation in a spontaneous connected speech utterance is shown in figure 3.1 below and for an imitated connected speech utterance in figure 3.2 below.

For both the imitated and spontaneous connected speech utterances, a combination of perceptual, waveform and spectrographic information was used to determine the precise phonetic transcription, thus, the acoustic information supported the auditory / perceptual based transcription. However, there are inherent difficulties in this type of analysis, where judgements have to be made based on the available information. In the imitated experimental phrase, the end of the /ŋ/ of "picking" was observable by a decrease in the energy associated with the /ŋ/ production and the onset of friction energy associated with the /s/ of "some". Where children omitted the word "some", precise identification of the end of the /ŋ/ was reached through a combination of repeated playback and study of the spectrogram to decide the endpoint in relation to the beginning of the following word.

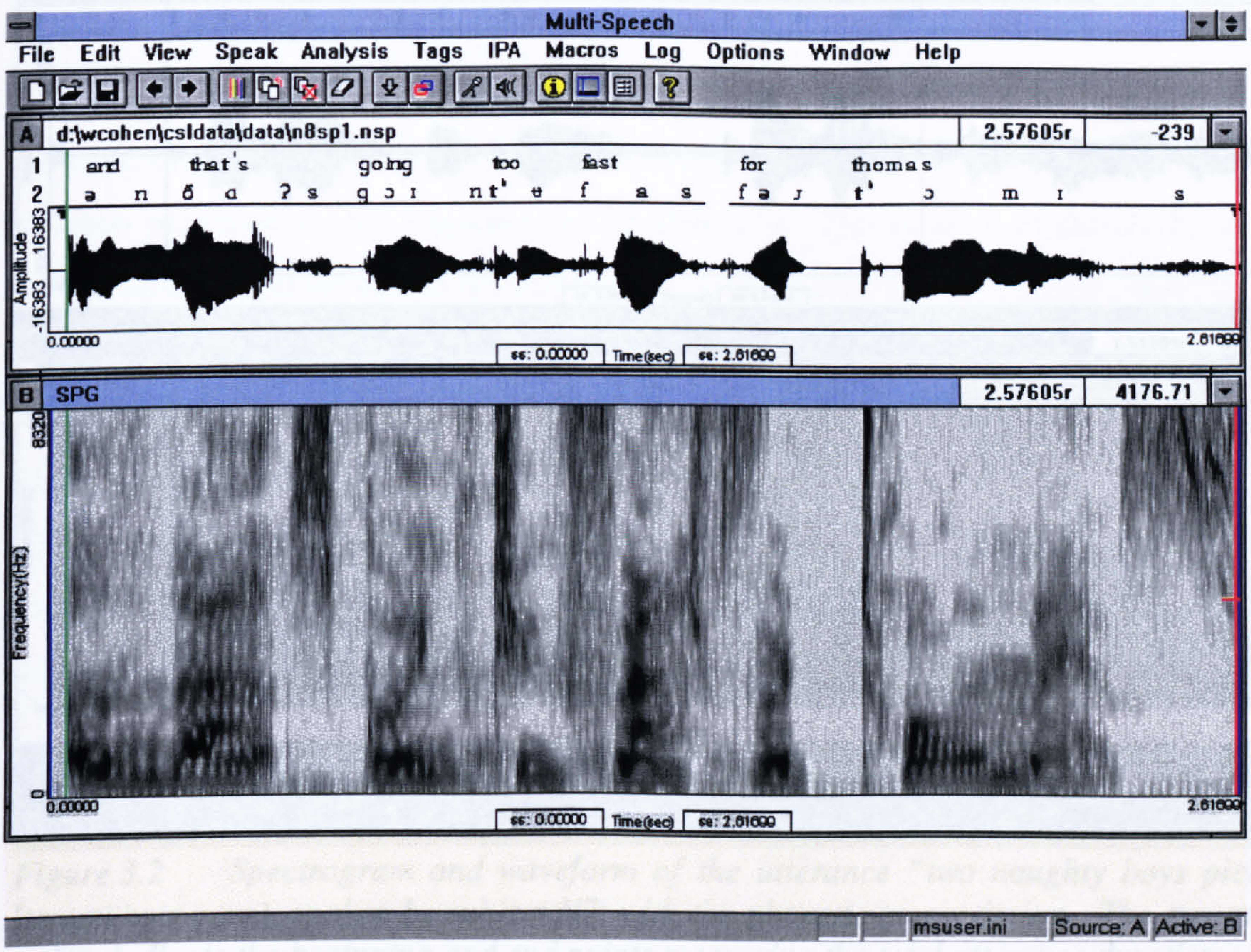

Figure 3.1 Spectrogram and waveform of the utterance "and that's going too fast for Thomas" [ən ðats goɪn tʉ fas fər tɔməs] *spoken by subject N8, with the phonetic transcription. The two marker points indicate the beginning and end points measuring the total utterance duration*

Articulation rate was calculated for each spontaneous and imitated utterance. The total duration of the pauses (in ms) was subtracted from the duration of the utterance (in ms), leaving a value representing total articulation time (in ms). By dividing the number of syllables by the total articulation time, a mean syllable rate is found. When this figure is multiplied by 1000, articulation rate in syll/s is found. The same calculation is used for articulation rate in seg/s, where mean segment rate is multiplied by 1000. Table 3.4 below summarises these calculations.

duration of utterance (ms)	total duration of pauses (ms)	total duration of articulation (ms)	number of syllables	number of segments	syllables/ second	segments/ second
X	**W**	**X-W = V**	**Y**	**Z**	**(Y/V) x 1000**	**(Z/V) x 1000**

Table 3.4 Calculation of articulation rate in syll/s and seg/s

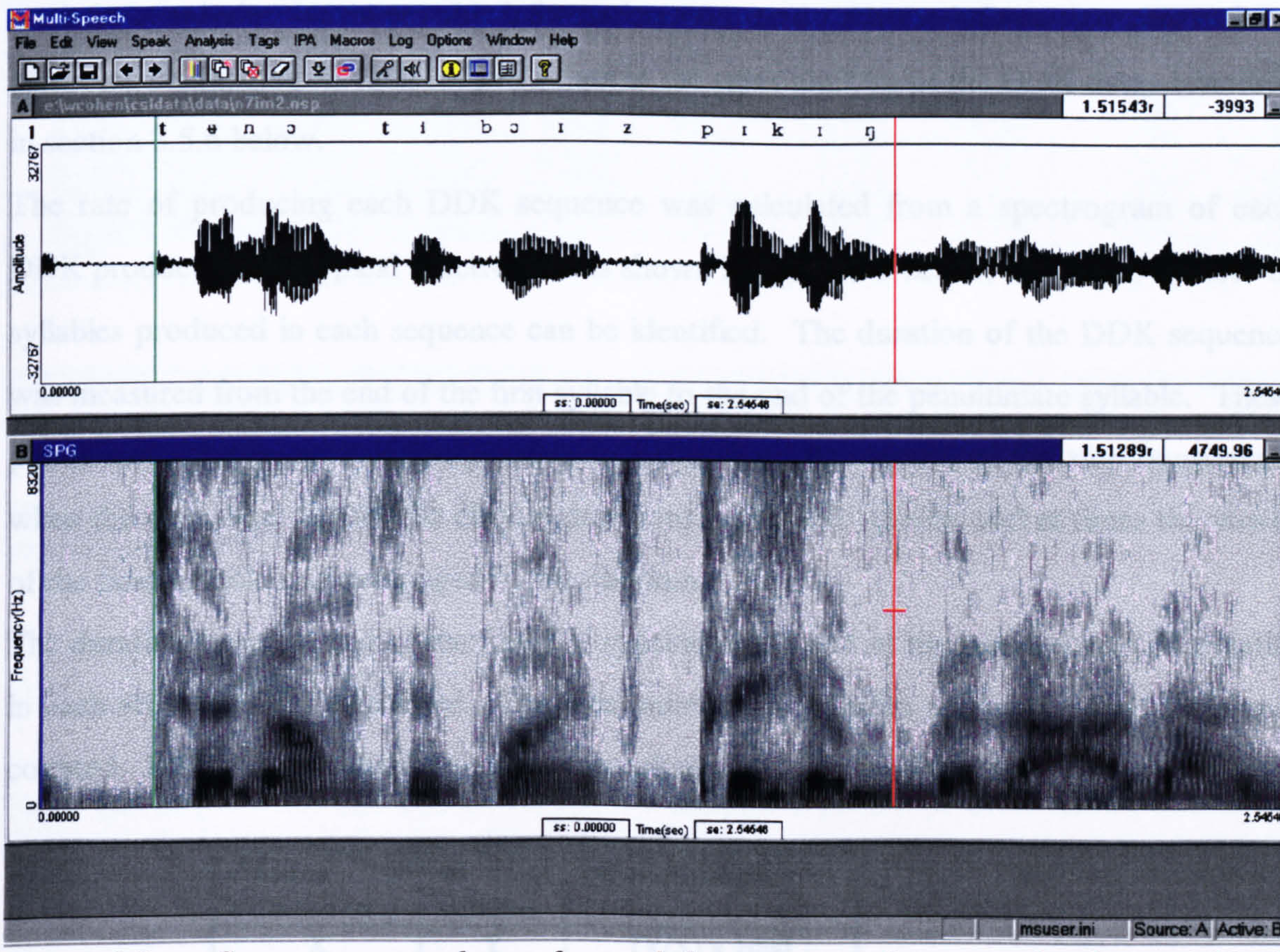

Figure 3.2 Spectrogram and waveform of the utterance "two naughty boys picking" [tʉ nɔti bɔɪz pɪkɪŋ], *spoken by subject N7, with the phonetic transcription. The two marker points indicate the beginning and end points measuring the total utterance duration*

Microsoft Excel software assisted in the analysis of articulation rate. By entering the total duration of each utterance, the total duration of all pauses > 250ms, the number of syllables and the number of segments, it was possible to obtain articulation rate in syll/s and seg/s for each of the eight spontaneous and eight imitated utterances for each subject from a spreadsheet template. The mean articulation rate for each subject was then calculated.

A total of 206 spontaneous connected speech utterances and 224 imitated connected speech utterances were analysed in this way across all twenty-eight subjects.

3.3.2.3 *DDK rate*

The phonetic transcription was used to determine each subject's ability to accurately repeat the target utterance. An accurate repetition was defined as one consisting of the CV sequence where the C was produced with the same place, manner and voicing characteristics as the model and the V was an appropriate unstressed voiced vowel (usually schwa). Where a subject mispronounced any segment within a trial, this was excluded from statistical analysis. However, this information was used with the information gained from phonological analysis of each subject's data in the error analysis of the DDK data, described in section 3.5.6 below.

The rate of producing each DDK sequence was calculated from a spectrogram of each DDK production. A typical spectrogram is shown in figure 3.3 below, where the number of syllables produced in each sequence can be identified. The duration of the DDK sequence was measured from the end of the first syllable to the end of the penultimate syllable. These points were chosen as it is not possible to judge from the release of the stop consonants when the consonant began (the closure duration) in the first syllable, and at times the vowel of the final syllable was prolonged by the children.

The duration from the end of the first CV syllable to the end of the penultimate CV syllable in each sequence was calculated. The total number of syllables within this time scale was counted. DDK rate in syllables/second was calculated using the formula in Table 3.5 below.

duration of sequence (ms)	no of syllables	syllables/second
X	**Y**	**(Y/X) x 1000**

Table 3.5 Formula used to calculate DDK rate in syll/s

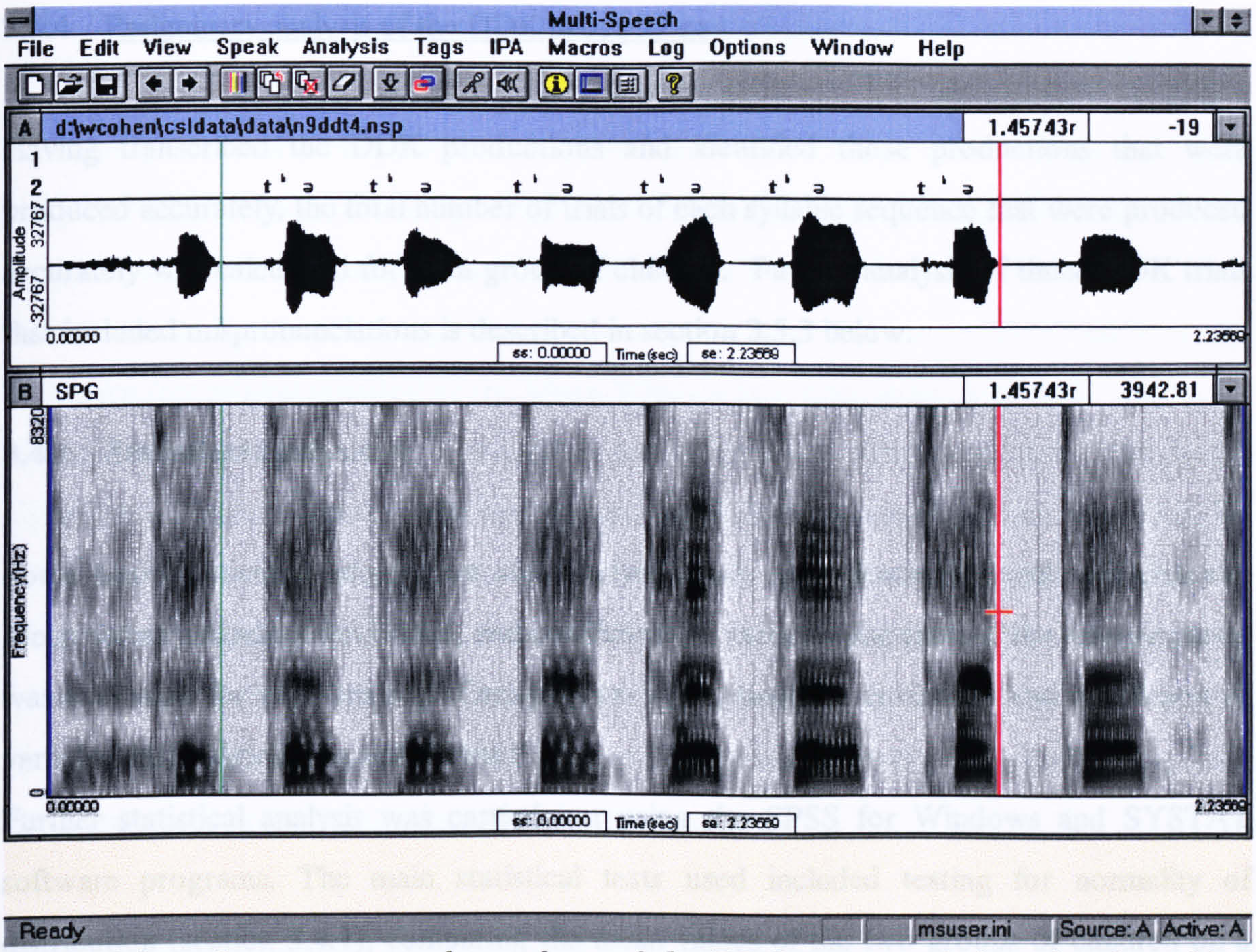

Figure 3.3 Spectrogram and waveform of the DDK sequence /tə/, spoken by subject N9, with the phonetic transcription. The two marker points indicate the beginning and end points measuring the total duration from the end of the first syllable to the end of the penultimate syllable.

3.3.3 Phonological analysis

From the single word and connected speech samples a profile of each child's consonant system was drawn up in the form of a consonant system inventory. A phonological analysis of each child's speech sound system was completed using the transcribed single word data. Pronunciation patterns were described using phonological process analysis (see chapter one, section 1.1.1). A percentage occurrence rate for each of these systemic and structural processes was calculated for the single word data, the imitated connected speech data and the spontaneous connected speech data. This allowed a comparison of each child's production skills in different contexts.

3.3.4 Preliminary analysis of the DDK productions

Having transcribed the DDK productions and identified those productions that were produced accurately, the total number of trials of each syllable sequence that were produced accurately was calculated for each group of children. Further analysis of those DDK trials that included mispronunciations is described in section 3.5.3 below.

3.4 Statistical analysis

Some basic statistical information was derived from the Microsoft Excel spreadsheets. Mean values, standard deviations, and coefficient of variation for each of the rate measures was evaluated for each subject. Group mean value, standard deviations and coefficient of variation information was also derived.

Further statistical analysis was carried out using the SPSS for Windows and SYSTAT software programs. The main statistical tests used included testing for normality of distribution (section 3.4.1), comparing the mean values of the two groups of children on a variety of measures (section 3.4.2), and investigating the relationship between various measures (section 3.4.3).

3.4.1 Testing for normality of distribution

All of the data values used for statistical analysis were tested for normality of distribution using the Kolmogorov-Smirnov test for normality of distribution. This statistical test, carried out using the SPSS software program, tests the null hypothesis that the sample comes from a normally distributed population. The aim of the analysis is to fail to reject the null hypothesis, identifiable by the resultant p value. Where this p value is not significant (i.e. $p > 0.05$) the null hypothesis is accepted, indicating that the sample is derived from a normally distributed population.

Where the sample was shown to derive from such a population, parametric statistical analysis was used. Where the null hypothesis was rejected, non-parametric statistical analysis was used.

3.4.2 Comparing the mean values of the two groups of children

Comparing the mean values on a variety of measures was carried out using the SPSS program. If the data was found to come from a normally distributed population, parametric statistical testing was possible, using the independent t-test. Where the data did not come from a normally distributed population, non-parametric tests were used, such as the Wilcoxon (for related samples) or the Mann-Whitney (for independent samples).

Where an independent t-test was carried out to evaluate whether or not there was a significant difference between the two groups of children on any of the rate measures, the SPSS for Windows program automatically tests for equality of variance. This test is used to help determine the homogeneity of variance of the two samples being tested. Where the Levene's test result is not significant, (i.e. $p > 0.05$) the t-test result is determined from the "equal variances" value of the resultant output. Where the Levene's test is significant, the t-test result is determined from the unequal variances value.

3.4.3. Investigating the relationship between various measures

The relationship between various measures was tested using a Pearson's correlation on the SPSS software program. In this test, a correlation coefficient is calculated to measure the strength of relationship between two variables. The p value of this correlation coefficient determines the strength of significance of this relationship, while the calculation of a 95% confidence interval demonstrates more precisely where the r value lies. In general, an r value of 0.7 or above is deemed to indicate a strong correlation, while an r value of 0.5 a moderate correlation and an r value of 0.3 or below, a weak correlation.

3.4.4 Investigating the proportion of accurately produced DDK targets in each group

A statistical test of proportions was carried out on the data, using SYSTAT software to determine whether there was a significant difference between the two groups in terms of the numbers of accurately produced DDK syllable trials achieved.

3.5 Data analysis in relation to the specified research questions

In relation to the research questions specified at the end of chapter one, a variety of analysis techniques were used in investigating each question. The following sections outline the procedures used to address each of these research questions.

3.5.1 Comparing the articulation rate of the two groups of children

The spontaneous and imitated connected speech samples were treated in the same way. A mean articulation rate in seg/s and syll/s for each child's dataset was calculated. This gave a total of four mean values for each child : mean articulation rate of the imitated connected speech sample in seg/s, mean articulation rate of the imitated connected speech sample in syll/s, mean articulation rate of the spontaneous connected speech sample in seg/s and a mean articulation rate of the spontaneous connected speech sample in syll/s. Standard deviations for each value were determined and the coefficient of variation calculated to give a percentage score showing the intra-subject variability associated with each value.
Group values were also determined, giving a group mean rate for each of the measures, a group standard deviation and a group coefficient of variation showing the inter-subject variability.

3.5.2 Comparing the DDK rates of the two groups of children

As pointed out in chapters one and two, one of the concerns with analysing DDK from disordered speakers is the extent to which any mispronunciations are included in rate analysis. For this reason, DDK rate was calculated for each of the repetition sequences twice. The DDK rate from all attempts at the repetition was calculated, and the DDK rate from the accurate productions only.

3.5.2.1 *All attempts of the DDK repetitions*

A mean DDK rate for each of the syllable sequences was evaluated for each child's DDK production. This gave a total of up to five mean values for each child : mean DDK rate for trials of /pə/, mean DDK rate for trials of /tə/, mean DDK rate for trials of /kə/, mean DDK rate for trials of /pətə/ and mean DDK rate for trials of /pətəkə/.

Independent t-tests were carried out on this data to evaluate whether or not there was a significant difference between the two groups of children on any of the measures. These t-tests were carried out using the SPSS software program.

3.5.2.2 *Accurate productions only*

Mean DDK rate for the accurate productions of each DDK repetition were evaluated for each child. As with the comparison of the DDK rate of all attempts of the DDK repetition, an independent t-test was carried out to evaluate whether or not there was a significant difference between the two groups of children on any of the accurately produced DDK trials. These t-tests were carried out using the SPSS software program.

3.5.3 Comparing the measure syll/s and the measure seg/s in the connected speech samples and calculating the mean number of segments produced per syllable by each child

Having calculated a mean articulation rate in seg/s and syll/s for each child in each of the connected speech samples, the relationship between each of these measures was investigated using a Pearson's correlation coefficient. Using the SPSS software analysis programme, this correlation was carried out to assess the correlation between syll/s and seg/s as measures of articulation rate. The analysis was carried out on the complete dataset, and for each of the two groups individually. This analysis was used to determine whether a correlation that appeared to exist between variables was statistically significant at the level of $p < 0.05$. The nearer the r value is to 1 or -1, the more highly the variables correlate.
This analysis was carried out on both the mean articulation rate values of each child's imitated and spontaneous connected speech samples.
It was possible also to evaluate the mean number of segments produced per syllable by each subject in each of the connected speech samples. This was calculated simply by counting the number of segments produced in each of the syllables in each utterance, deriving a mean number of syllables/segment for each utterance and a mean for the imitated and the spontaneous utterances.
Independent t-tests were used to determine whether there was a statistically significant difference between the number of segments/syllable in the P children and the N children.

Independent t-test were used to determine also whether there was a statistically significant difference between the number of segments/syllable in the spontaneous connected speech and the imitated connected speech for each group of children.

3.5.4 Comparing the articulation rates in seg/s of the two connected speech samples

Having calculated a mean articulation rate in seg/s for each child in each of the connected speech samples, the relationship between the measure in each of the two connected speech contexts was investigated using a Pearson's correlation coefficient. Using the SPSS software analysis programme, a Pearson's correlation was carried out to assess the correlation between the articulation rates in the two connected speech samples. This correlation was carried out on the complete dataset, and for each of the two groups individually. This analysis was used to determine whether a correlation that appeared to exist between variables was statistically significant at the level of $p < 0.05$. The nearer the r value is to 1 or -1, the more highly the variables correlate.

3.5.5 Investigating the relationship between articulation rate in syll/s and DDK rate of the accurate DDK productions

Having calculated articulation rate in syll/s for the imitated and spontaneous connected speech samples, and the DDK rate of the accurately produced DDK trials, the relationship between the two rate measures was investigated using a Pearson's correlation coefficient. Using the SPSS software analysis programme, this correlation was carried out to assess the correlation between articulation rate and DDK rate of each of the accurately produced syllable sequences. This correlation was carried out on the complete dataset, and for each of the two groups individually. This analysis was used to determine whether a correlation that appeared to exist between variables was statistically significant at the level of $p < 0.05$. The nearer the r value is to 1 or -1, the more highly the variables correlate.

3.5.6 Error analysis of the imitated connected speech utterances and the DDK data

From the phonetic and phonological analyses of the single word data, imitated connected speech data, spontaneous connected speech data and the DDK data, an analysis of the error patterns made in the imitated utterances and DDK productions was made. The error analysis of the DDK data was split into three sections, analysis of the errors in the monosyllabic data, analysis of the errors in the bisyllabic data and analysis of the errors in the polysyllabic data.

3.5.6.1 *Error analysis of the imitated connected speech utterances*

Specific patterns of simplification processes produced by each child in the imitated connected speech utterances were compared to those produced by the same child in the single word and spontaneous connected speech data. Occurrence of a specific error of pronunciation on at least one occasion in any of the speech contexts was determined as indication of its presence in the child's speech production system. From this comparison it was possible to identify which children produced pronunciation patterns with specific errors that were not present in any other context.

3.5.6.2 *Error analysis of the monosyllabic data*

The errors produced by each child in each of the monosyllabic DDK trials were compared with the phonological profile of that child. Three possible patterns of production in the DDK data were identified. The sequence could be produced accurately without any error. This was defined as a correct production.

Where a mispronunciation occurred in a DDK sequence and this same specific pattern of mispronunciation was present in any of the single word or connected speech data, this error was defined as predictable on the basis of single word and connected speech ability. The error pattern had only to be present once in the single word and connected speech samples for its presence in the DDK tasks to be considered predictable. For example, where there was evidence of a child using the systemic simplification process "fronting" velar targets to alveolars in his or her single word or connected speech, and this process occurred also in his or her DDK productions for the velar sequence /kə/, this would be classified as a predictable error. Where the mispronunciation occurred only in the DDK data, and the same specific error pattern was not evident in any of the other speech data, the error was defined as non-predictable on the basis of single word and connected speech ability.

Percentage occurrence of correct, predictable errors and non-predictable errors for each child was calculated for this data. Group totals were derived from this information.

3.5.6.3 *Error analysis of the bisyllabic data*

As with the monosyllabic sequences, the mispronunciations observed in the transcriptions of the bisyllabic DDK sequences were split into three categories, correct, predictable and non-predictable productions. The same criteria were used to define each of these as with the monosyllabic productions.

Percentage occurrence of correct, predictable errors and non-predictable errors for each child was calculated for this data. Group totals were derived from this information.

The bisyllabic DDK task involves alternating two places of consonant articulation. The data was also therefore inspected with regard the ability of each child to alternate the two places of articulation (bilabial and alveolar) in the same order as in the model given. The total number of trials that were produced by each group of children with both places of articulation in the correct order was calculated. The total number of trials produced by each group of children with both places of articulation produced in the wrong order was calculated. The total number of trials produced with only one place of articulation by each group children of was calculated. These figures were converted into percentages for each group of children.

3.5.6.4 *Error analysis of the polysyllabic data*

As with the monosyllabic and bisyllabic sequences, the mispronunciations observed in the transcriptions of the polysyllabic DDK sequences were split into three categories, correct, predictable and non-predictable productions. The same criteria were used to define each of these as with the monosyllabic and bisyllabic productions.

Percentage occurrence of correct, predictable errors and non-predictable errors for each child was calculated for this data. Group totals were derived from this information.

The polysyllabic DDK task involves alternating three places of consonant articulation. The data was also therefore inspected with regard the ability of each child to alternate the three places of articulation (bilabial, alveolar and velar) in the same order as in the model given. The total number of trials that were produced by each group of children with all three places of articulation in the correct order was calculated. The total number of trials produced with all three places of articulation produced in the wrong order by each group of children was calculated. The total number of trials produced with two places of articulation by each group of children was calculated. The total number of trials produced with only one place of articulation by each group of children was calculated. These figures were converted into percentages for each group of children.

3.5.6.5 *Comparing the stop consonants perceived as voiced and the stop consonants perceived as voiceless*

From the transcribed data of the mispronunciations in the DDK data it was noted that many of the non-predictable errors tended to involve the target stop consonant being perceptually identified as the voiced cognate instead of the voiceless cognate. The spectrographic display of the trials where a stop consonant was perceived as voiced were inspected. In some instances continuous voicing was noted in the trials, where there was evidence of voicing before the release of the stop consonant in the CV syllables. Since the CV syllables were produced in a continuous string, precise measurement of voice onset time was not possible as the stop consonants were produced in the intervocalic position. The period of time between the release of the stop and the onset of the first formant of the vowel was measured for each of the trials, both where the stop consonant had been perceived as voiced and as voiceless for each of the subjects. This period, referred to as "F1 onset time" (hereafter referred to as F1OT) was measured in those subjects who produced a stop consonant that was perceived as voiced in the /pə/ sequence (N6, P1, P3 and P7), in the /tə/ sequence (N14, P1, P3 and P5), in the /kə/ sequence (N6, P1, P3 and P5) and in the /pətə/ sequence (N6, P1 and P5). Both stops perceived as voiced and stops perceived as voiceless were measured for these subjects where possible. Where both the release of the stop and any aspiration phase were not clear on the display this period of time was assigned a value of zero. (If the more usual VOT measurements were being taken this would indicate pre-voicing and a negative VOT value). Figure 3.4 below shows an example of the display. In this figure, where the trial was perceived as /gəgəgəgəgəgə/, the F1OT of each stop was measured, from the release of the stop to the onset of the F1 of the vowel, as shown by each of the two markers.

The F1OT for those stops perceived as voiced and those stops perceived as voiceless was compared using statistical analysis using the SPSS software program. Both paired t-tests and the non-parametric Wilcoxon test of significance were used to determine the level of statistically significant difference between the F1OT of those targets perceived as voiced and the F1OT of those targets perceived as voiceless.

Thus, the acoustic and statistical analysis was used to confirm the perceptual identification of those stops perceived as voiced.

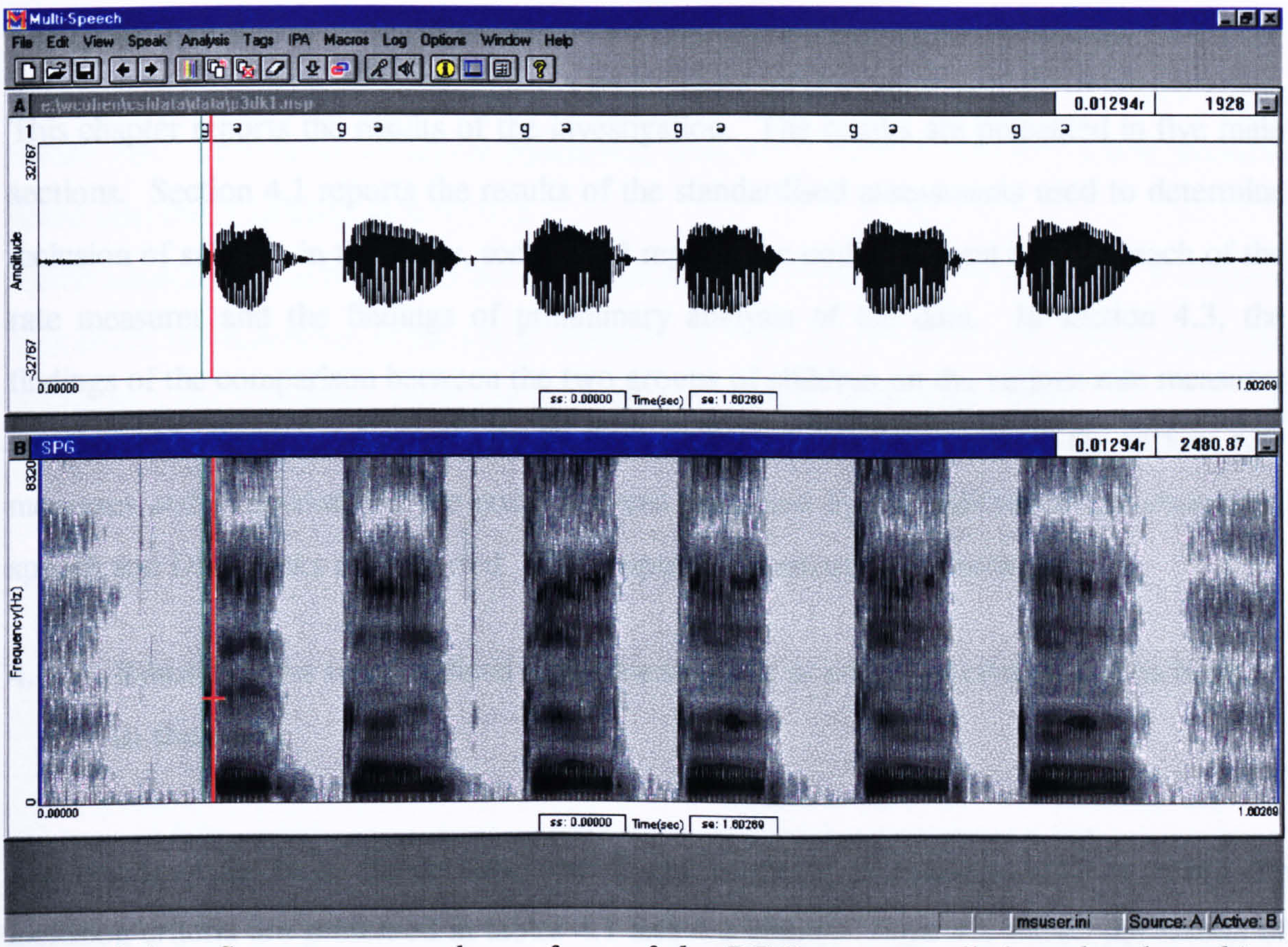

Figure 3.4 Spectrogram and waveform of the DDK sequence /kə/, spoken by subject P3. The first marker point (in green) indicates the release of the first stop. The second (in red) indicates the beginning of F1 of the following vowel. The duration between these two points is F1OT.

The results of all the above analyses are presented in the following chapter.

Chapter Four Results

This chapter reports the results of the investigation. The results are presented in five main sections. Section 4.1 reports the results of the standardised assessments used to determine inclusion of subjects in the study, section 4.2 reports the coding system used for each of the rate measures and the findings of preliminary analysis of the data. In section 4.3, the findings of the comparison between the two groups of children on the various rate measures are reported. Section 4.4 reports the findings on the relationships between the various rate measures and in section 4.5 the error patterns produced by the children in the connected speech and DDK tasks are reported. The chapter is summarised in section 4.6.

4.1 Results of the standardised assessments used as selection criteria for inclusion in the study

The results of the three standardised speech and language assessments used to satisfy the inclusion criteria are presented in tables 4.1 and 4.2 below. Table 4.1 shows the results of these assessments of the N children and table 4.2 the results for the P children. The tables show the subject code, age at assessment, standard score on the Edinburgh Articulation Test (EAT, Ingram et al 1971), standard score on the comprehension section of the Reynell Developmental Language Scale (RDLS, Reynell 1985) and information and grammar raw scores and age equivalents on the Renfrew Action Picture Test (RAPT, Renfrew 1988). All the children presented with expressive and receptive language skills that were not more than one standard deviation below the mean, with the possible exception of subject P8 whose score on the grammar section of the RAPT was lower than for any other child. The standard scores on the EAT show that the N children had pronunciation skills that were at or above the mean (mean = 100), while the P children had pronunciation skills that were at least one standard deviation below the mean (one standard deviation is equivalent to 15, therefore, a standard score of 85 is one standard deviation below the mean).

The scores on each of the tests for the children in each of the two groups were compared using independent t-tests. This revealed that while each of the children in both groups presented with language skills within 6 months of their chronological age, the group means for the P children tended to be lower than the group means for the N children. The P children as a group presented with a lower raw score on the RAPT grammar section than the N children ($p < 0.05$) and a lower standard score on the RDLS ($p < 0.05$). On the information section of the RAPT there was no significant difference between the mean raw scores of the two groups of children ($p > 0.05$). The difference between the standard scores on the EAT were however highly significant, with the P children having a lower standard score than the N children ($p < 0.005$).

These results indicate that while the main feature differentiating the two groups of children concerned pronunciation skills, the P children as a group tended to have lower language scores than the N children whilst still presenting within age appropriate limits.

Subject	**Age**	**EAT Standard Score**	**RDLS Standard Score**	**RAPT - information standard score and age equivalent**		**RAPT - grammar standard score and age equivalent**	
N1	3;10	153	1.6	22	3;6-3;11	16	3;6-3;11
N2	4;2	137	1.7	35	7;0-7;5	29	7;0-7;5
N3	4;6	114	1.1	35	7;0-7;5	24	5;6-5;11
N4	4;3	103	0.9	33	6;0-6;5	20	4;0-4;5
N5	4;5	120	1.1	31	5;6-5;11	16	4;0-4;5
N6	4;6	130	-0.1	29.5	4;6-4;11	21	4;6-4;11
N7	4;0	100	1.5	33	6;0-6;5	33	>8;0
N8	4;7	125	1.0	36	7;6-7;11	23	5;0-5;5
N9	4;5	129	0.8	35	7;0-7;5	30	7;6-7;11
N10	4;10	137	0	28.5	4;6-4;11	22	4;6-4;11
N11	4;0	133	0.9	32.5	6;0-6;5	23	5;0-5;5
N12	4;0	133	0.6	26.5	4;0-4;5	15	3;6-3;11
N13	4;4	145	1.1	30	5;0-5;5	25	5;6-5;11
N14	4;11	114	0.8	33.5	6;0-6;5	26	6;0-6;5
Group Mean	4;4	118	0.9	33.5		23	

Table 4.1 Results of the standardised assessments for Group N children

Subject	**Age**	**EAT Standard Score**	**RDLS Standard Score**	**RAPT - information standard score and age equivalent**		**RAPT - grammar standard score and age equivalent**	
P1	4;0	73	1.8	38	>8;0	18	4;0-4;5
P2	3;9	77	0.8	36	7;6-7;11	24	5;6-5;11
P3	4;2	80	0.6	38	>8;0	25	6;0-6;5
P4	4;6	66	0.4	28.5	4;6-4;11	18	4;0-4;5
P5	3;11	84	0.6	31.5	5;6-5;11	15	3;6-3;11
P6	4;9	79	0	31	5;6-5;11	23	5;0-5;5
P7	3;10	84	0.9	24.5	3;6-3;11	12	<3;6-3;11
P8	3;9	53	-0.3	23	3;6-3;11	6	<3;6-3;11
P9	5;3	37	0.4	31.5	5;6-5;11	19	4;6-4;11
P10	5;1	64	0.7	32	5;6-5;11	20	4;6-4;11
P11	5;1	40	0.2	33	5;6-5;11	19	4;6-4;11
P12	4;6	57	0.5	29.5	4;6-4;11	22	4;6-4;11
P13	3;8	73	-1	24.5	3;6-3;11	10	<3;6-3;11
P14	3;9	75	0.3	24	3;6-3;11	14	3;6-3;11
Group Mean	4;3	67	0.4	30		17.5	

Table 4.2 Results of the standardised assessments for Group P children

While the results of the EAT (Ingram et al 1971) show that the two groups of children differ by one standard deviation on their scores for the articulation test, this assessment does not profile the developmental patterns of the children's phonological abilities. Further single word data collected using the Metaphon Screening Pack (Dean et al 1990) was used to profile each of the children's phonological skills with reference to the simplification processes associated with normal phonological development.

The percentage of children in each of the two groups who exhibited each of the simplification processes was calculated. Figures 4.1 and 4.2 below show the results of this analysis, where it is evident that a greater proportion of P children exhibited a greater number of systemic and structural simplification processes than N children, thus confirming their status as phonologically disordered. There is one systemic process that is the exception to this, that where the fricative /θ/ is simplified to the fricative /f/, a number of N children (more than P children) exhibit this process. This is however a developmentally age appropriate simplification for all the children in the investigation. A number of P children did however delete this consonant or produce the fricative as a stop consonant.

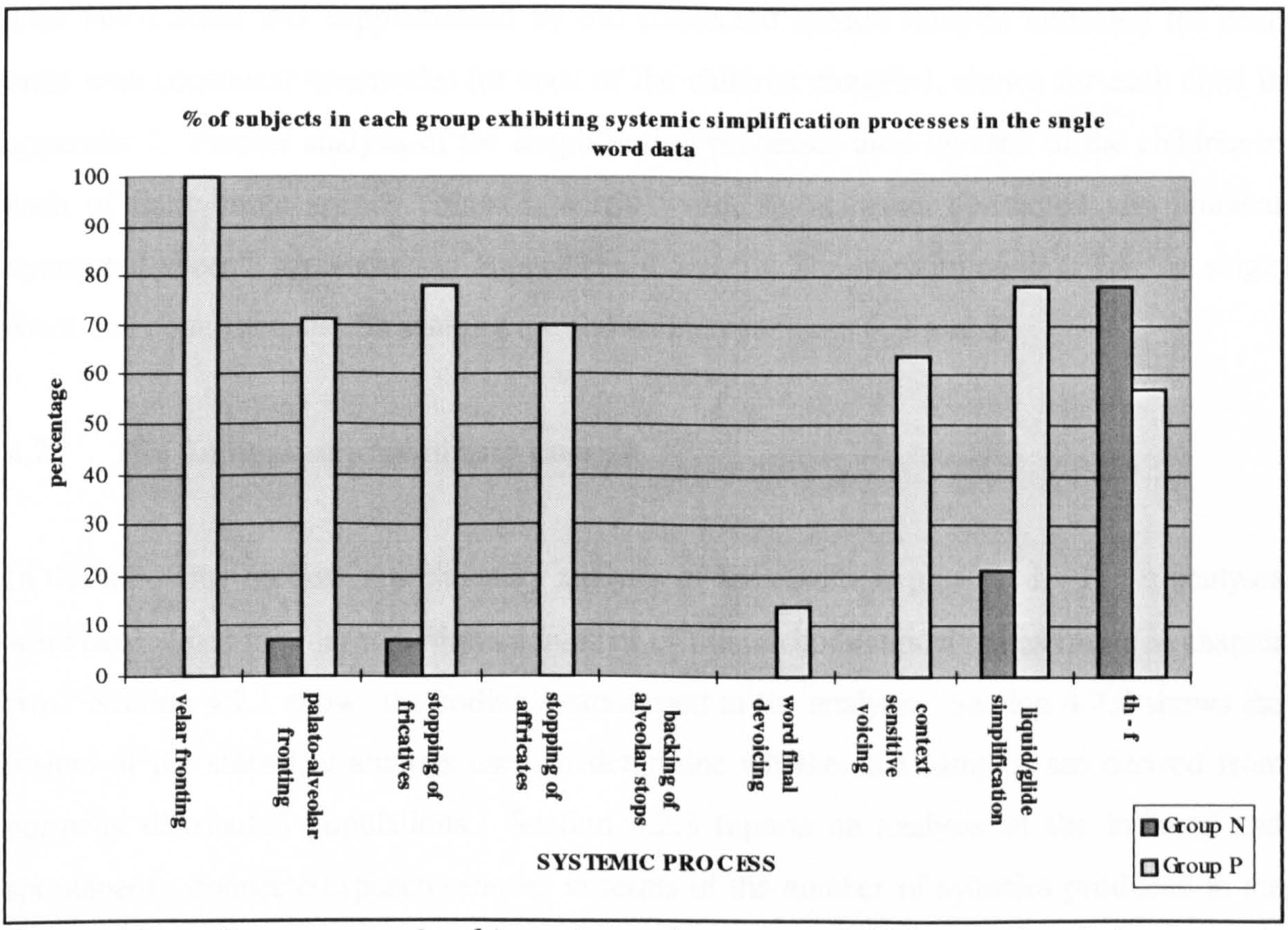

Figure 4.1 Percentage of subjects in each group exhibiting each of the systemic simplification processes

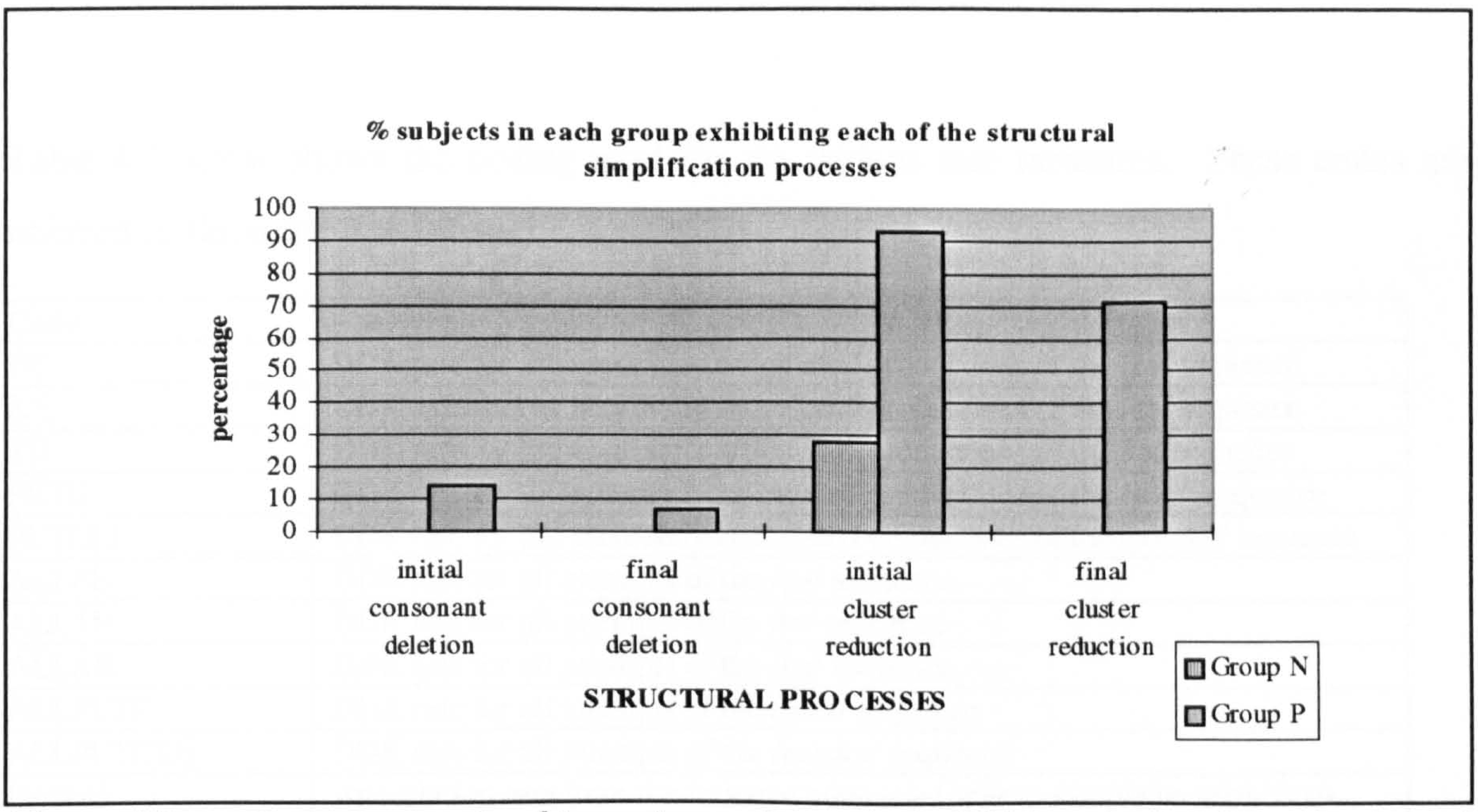

Figure 4.2 Percentage of subjects in each group exhibiting each of the structural simplification processes

This information was supplemented by the connected speech samples collected for each child with consonant inventories for each of the children compiled, shown for each child in appendix 3. Further analysis of the simplification processes used by each of the children in each of these three speech contexts, single word, spontaneous connected and imitated connected speech, are shown in appendices 4 and 5. The transcribed data for the single word and connected speech samples are shown in appendices 6, 7 and 8.

4.2 The findings of preliminary analysis

In the following section, a preliminary analysis of the results is presented. These analyses were carried out in order to address a number of the methodological issues raised in chapter two. Section 4.2.1 shows the coding system used in the analysis. Section 4.2.2 shows the results of the statistical analysis used to determine whether the samples are derived from normally distributed populations. Section 4.2.3 reports an analysis of the imitated and spontaneous connected speech samples in terms of the number of syllables produced in the utterances. Section 4.2.4 describes the proportion of accurately produced DDK productions for each of the monosyllabic, bisyllabic and polysyllabic repetition sequences for the two groups of children.

4.2.1 The coding system used to describe the various rate measures

Table 4.3 below shows the coding used for the various rate measures. These codes are referred to throughout the thesis.

Code	Measure
PE	DDK rate for the accurately articulated productions of the /pə/ sequence
KE	DDK rate for the accurately articulated productions of the /kə/ sequence
TE	DDK rate for the accurately articulated productions of the /tə/ sequence
PETE	DDK rate for the accurately articulated productions of the /pətə/ sequence
PETEKE	DDK rate for the accurately articulated productions of the /pətəkə/ sequence
ALLPE	DDK rate for all attempts of the /pə/ sequence
ALLTE	DDK rate for all attempts of the /tə/ sequence
ALLKE	DDK rate for all attempts of the /kə/ sequence
ALLPETE	DDK rate for all attempts of the /pətə/ sequence
ALLPETEKE	DDK rate for all attempts of the /pətəkə/ sequence
IMSEG	Articulation rate from the imitated connected speech sample in segments/s
IMSYL	Articulation rate from the imitated connected speech sample in syllables/s
SPSEG	Articulation rate from the spontaneous connected speech sample in segments/s
SPSYL	Articulation rate from the spontaneous connected speech sample in syllables/s

Table 4.3 Coding system used for the various rate measures

4.2.2 Ensuring that the samples come from normally distributed populations

It is important to ensure that the samples are derived from normally distributed populations in order to use parametric statistical tests. Using a one-sample Kolmogorov-Smirnov Test, the null hypothesis that a sample comes from a normally distributed population is tested. In this case, the statistical analysis aims to fail to reject the null hypothesis. For this to occur, the p value of the analysis should not be significant (i.e. $p > 0.05$).

As can be seen in table 4.4, with the exception of PETEKE for group P (where there is insufficient data for analysis), none of the p values are significant, thus the samples come from normally distributed populations, and are suitable for parametric statistical analysis.

Measure	Group N Kolmogorov-Smirnov p value	Group P Kolmogorov-Smirnov p value
TE	0.8479	0.6382
KE	0.6051	0.9551
PE	0.9846	0.6385
PETE	0.6835	0.9993
PETEKE	0.9597	insufficient data
ALLTE	0.5156	0.6526
ALLKE	0.5675	0.6470
ALLPE	0.3492	0.5448
ALLPETE	0.7199	0.7370
ALLPETEKE	0.6065	0.9356
IMSEG	0.9997	0.9786
IMSYL	0.9207	0.9123
SPSEG	0.9908	0.9224
SPSYL	0.6551	0.8387

Table 4.4 Results of the Kolmogorov-Smirnov test for normality of distribution

4.2.3 Comparing the utterance lengths of the two connected speech samples for each group of children.

It was pointed out in chapter two, sections 2.1.1.1 that length of utterance can affect articulation rate. Steps were taken in the methodological design of the study to measure like samples of speech in terms of utterance length.

Tables 4.5 and 4.6 show the number of utterances produced by each child and the mean number of syllables per utterance for each subject from each group in the two connected speech samples. A group mean is also given.

Despite the methodological design, where spontaneous utterances of similar length to the imitated utterances were selected, some of the children produced utterances that were longer. Thus, it is clear from tables 4.5 and 4.6 below that the spontaneous utterances were of greater length than the imitated utterances for some of the children in each group.

There is little difference between the length of the imitated utterances of the two groups of children and the length of the spontaneous utterances of the two groups of children, thus the comparison between articulation rate measures in the two subject groups was carried out on like data.

Subject	Imitated Speech		Spontaneous Speech	
	number of utterances analysed	mean number of syllables	number of utterances analysed	mean number of syllables
N1	8	7.00	8	7.25
N2	8	7.00	8	6.75
N3	8	7.13	8	6.38
N4	8	8.13	8	8.00
N5	8	5.88	8	5.00
N6	8	6.25	8	9.25
N7	8	6.25	8	7.00
N8	8	7.00	8	7.50
N9	8	6.00	8	8.00
N10	8	6.25	8	6.75
N11	8	5.88	8	8.88
N12	8	6.38	5	7.20
N13	8	5.38	8	6.75
N14	8	6.25	8	7.75
Total no	112		97	
Group Mean		6.48		7.32

Table 4.5 Mean number of syllables per utterance for the imitated and selected spontaneous connected speech samples for each of the Group N children individually, and the group means as a whole

Subject	Imitated Speech		Spontaneous Speech	
	number of utterances analysed	mean number of syllables	number of utterances analysed	mean number of syllables
P1	8	5.75	8	8.50
P2	8	5.38	8	7.00
P3	8	6.00	8	6.88
P4	8	5.88	8	7.25
P5	8	5.13	8	7.75
P6	8	6.00	8	6.88
P7	8	7.63	8	6.75
P8	8	5.00	4	6.00
P9	8	5.13	7	6.57
P10	8	6.00	3	6.33
P11	8	6.00	5	7.00
P12	8	5.88	6	7.00
P13	8	4.50	8	7.75
P14	8	4.63	8	7.00
Total no	112		109	
Group Mean		5.64		7.05

Table 4.6 Mean number of syllables per utterance for the imitated and selected spontaneous connected speech samples for each of the Group P children individually, and the group means as a whole

4.2.4 Proportion of accurately produced DDK productions

In chapter two, section 2.2.3 the rationale for using only accurately produced repetitions to derive DDK rate was discussed. An accurately produced DDK sequence is one where the stop consonant was perceived as being realised with the correct place and manner of articulation and the correct voicing status. With each stop consonant, an unstressed schwa vowel was also perceived following each consonant.

Table 4.7 shows the number of trials for each syllable sequence that were accurately produced by each group of children, out of the total number of trials produced. It is evident that the P children produced fewer accurate DDK productions than N children. The P children were able to produce a far greater proportion of /pə/ repetitions accurately than any of the other sequences.

Sequence	Group N - number of trials produced accurately	Group P - number of trials produced accurately
/pə/	68/70	50/70
/tə/	69/70	36/68
/kə/	69/70	20/70
/pətə/	66/70	29/67
/pətəkə/	37/70	1/70

Table 4.7 Total number of trials produced accurately by each group for each DDK sequence

Statistical analysis supports this finding. The proportion of children in each group who could accurately produce the sequences was compared. The results of this statistical test of proportions, detailed in table 4.8 show that there is a significant difference in the proportion of children in each group who could accurately produce the sequences /tə/, /kə/, /pətə/ and /pətəkə/. This is not the case for productions of /pə/, where the proportion of children in each group who could accurately produce this target was similar. In this test, the null hypothesis "the population proportion of N children = the population proportion of disordered children" is tested. Where the t value of the resultant calculation is greater than the critical value for t, the null hypothesis is rejected.

DDK sequence	*t* value	critical value of *t*	95% CI
/pə/	1.10189	2.0555	-0.073, 0.215
/tə/	2.1667	2.0555	0.015, 0.55
/kə/	2.9762	2.0739	0.152, 0.845
/pətə/	3.0544	2.0555	0.164, 0.836
/pətəkə/	3.432	2.0555	0.26, 1

Table 4.8 Results of the statistical test of proportions

Further illustration of this point is shown in figures 4.3 to 4.7, which illustrate the percentage of accurate productions that each group of children made for each DDK syllable sequence. These figures show that the P children make fewer errors on the /pə/ syllable (figure 4.3) than on the other syllables (figures 4.4 to 4.7), while the N children make fewer errors than the P children overall.

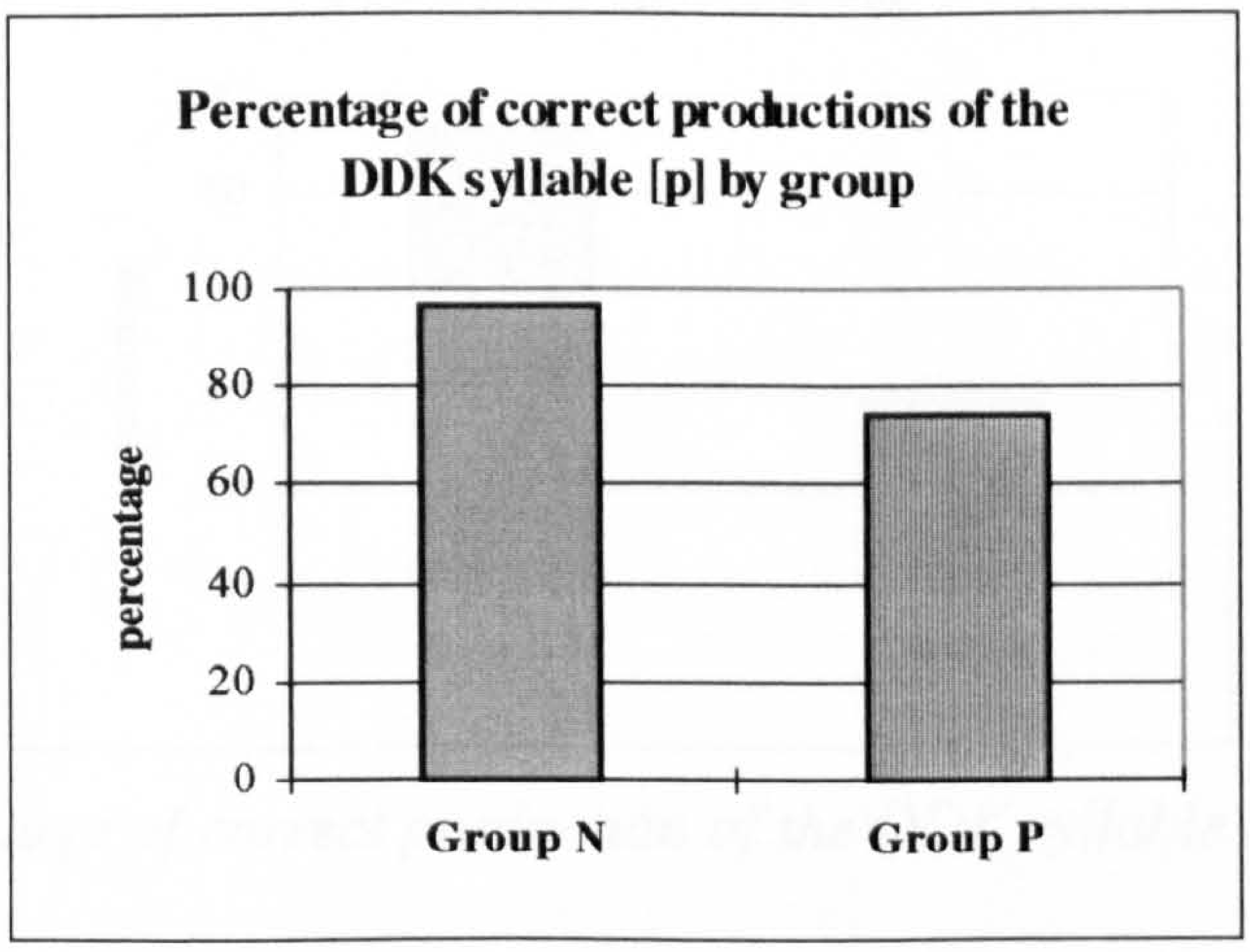

Figure 4.3 Percentage of correct production of the DDK syllable /pə/ by group

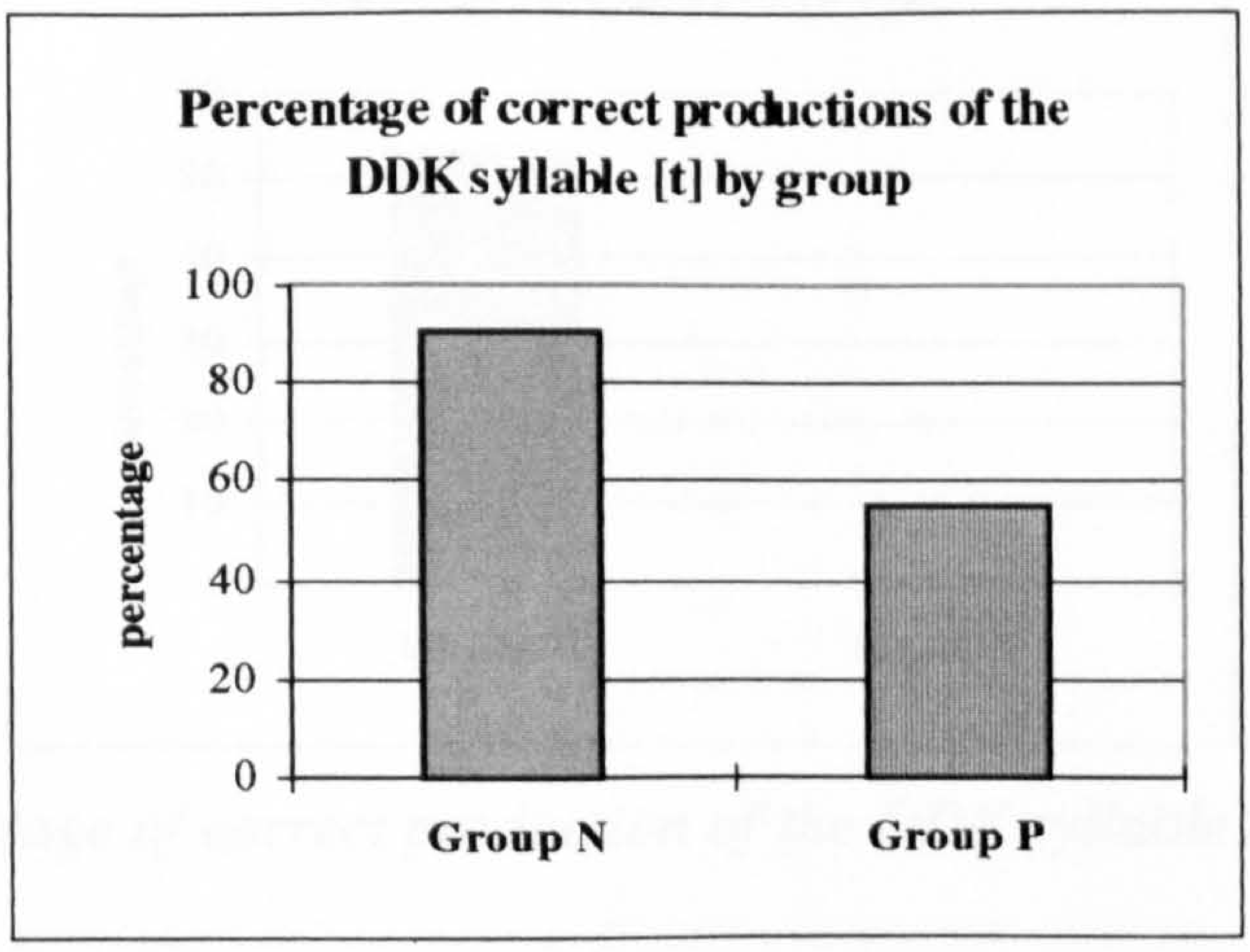

Figure 4.4 Percentage of correct production of the DDK syllable /tə/ by group

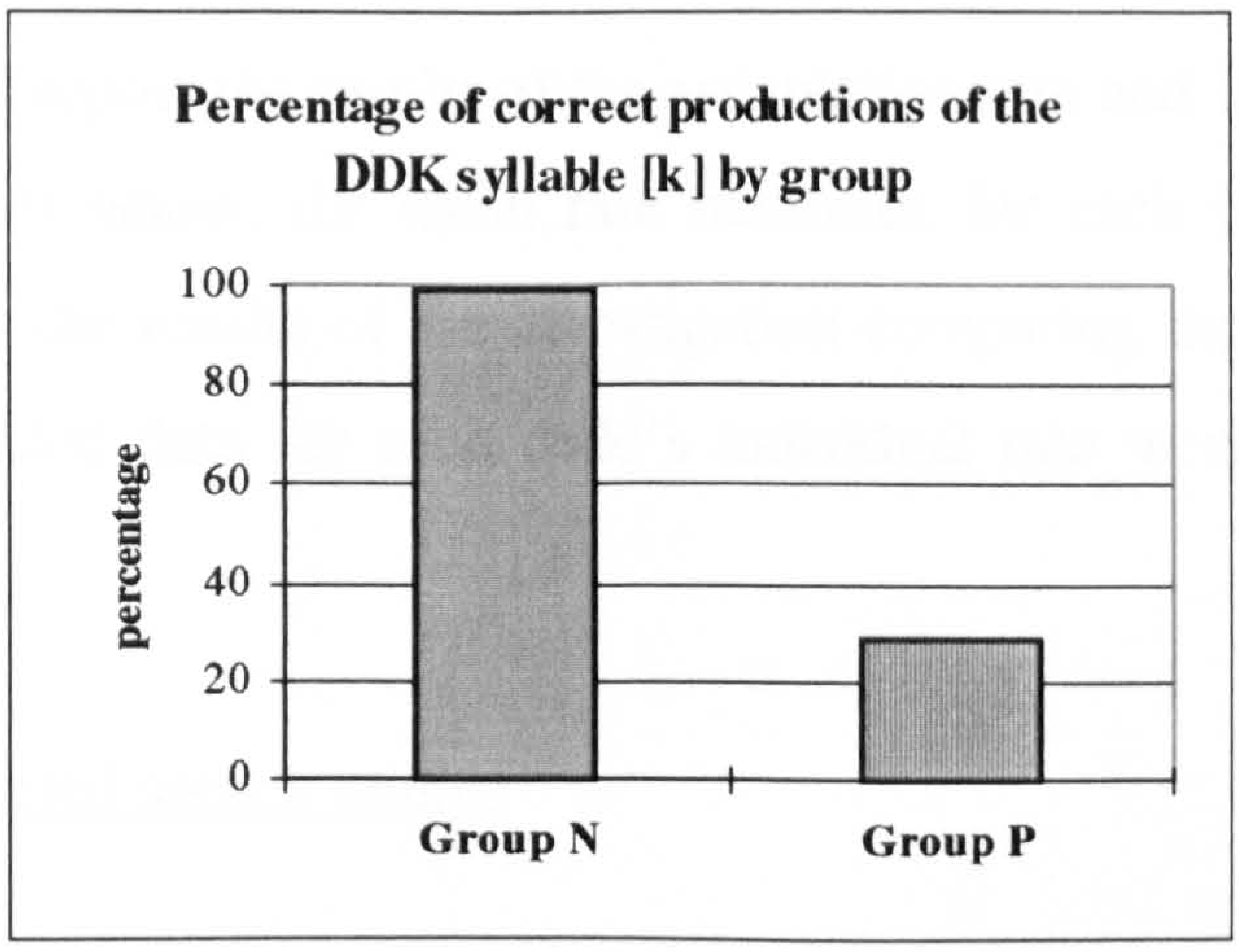

Figure 4.5 *Percentage of correct production of the DDK syllable /kə/ by group*

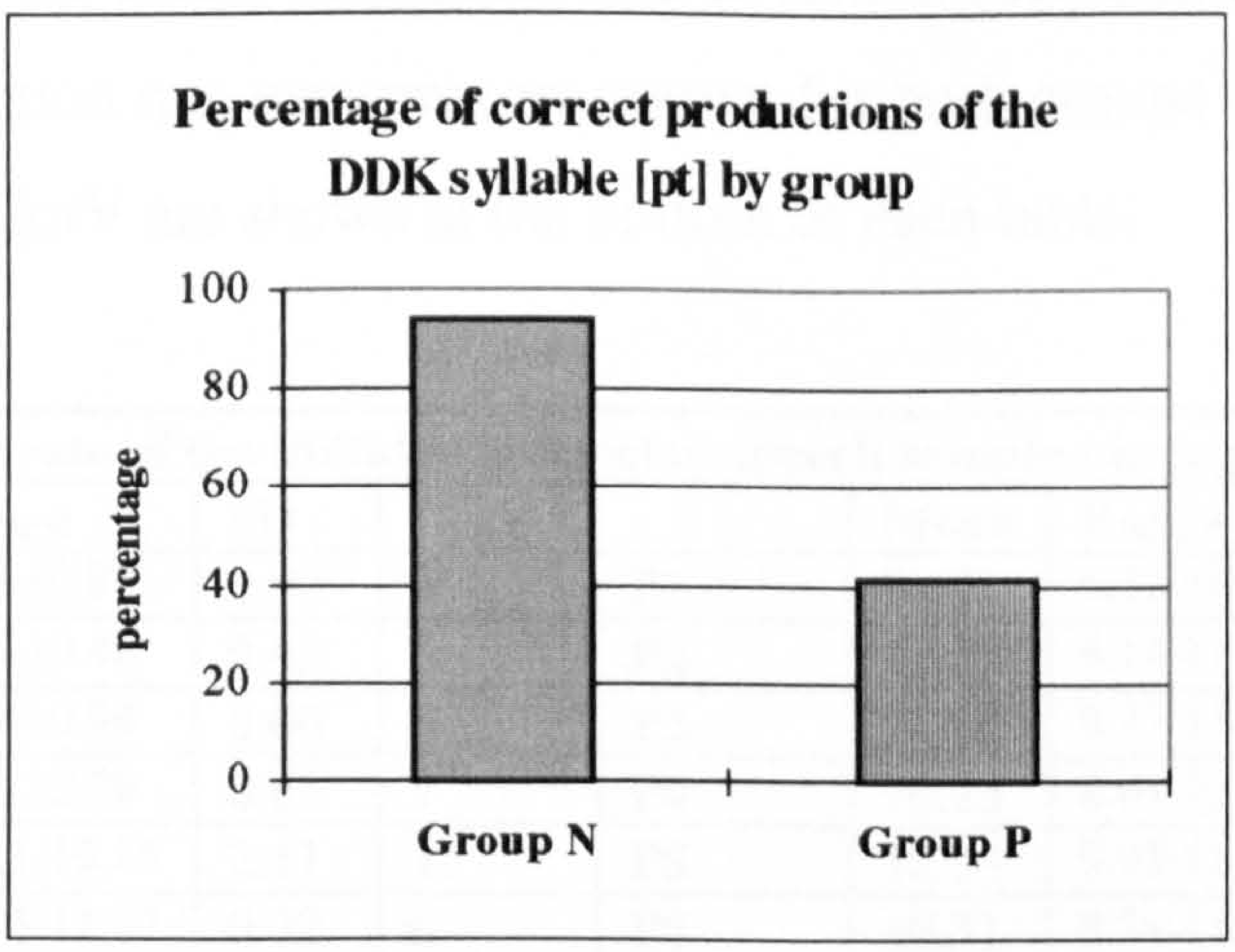

Figure 4.6 *Percentage of correct production of the DDK syllable /pətə/ by group*

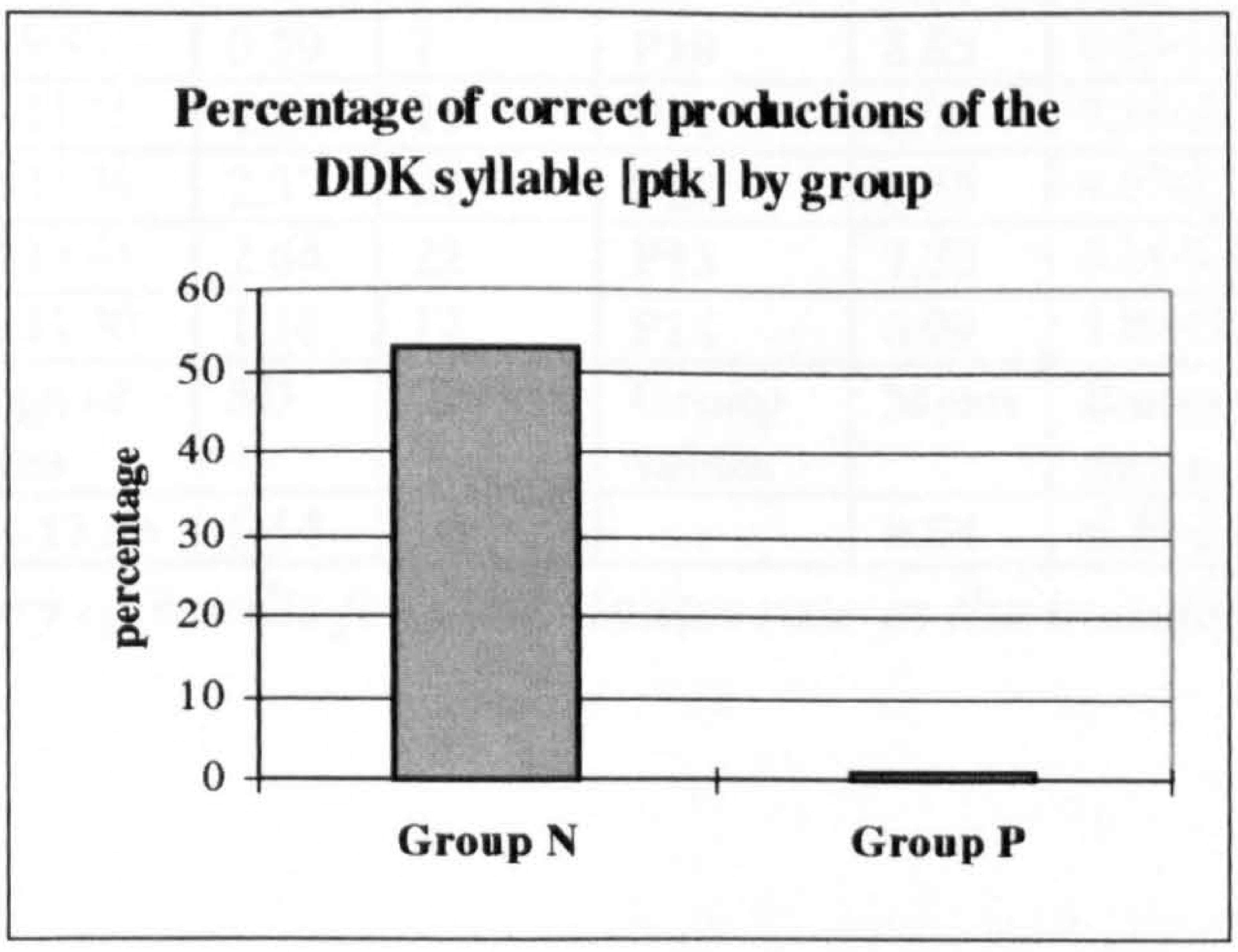

Figure 4.7 *Percentage of correct production of the DDK syllable /pətəkə/ by group*

4.3 Results of the articulation rate and DDK rate measures

The following sections report the results of the articulation rate and DDK rate measures. In each of the subsections below, the mean rate measures for each of the two groups are presented followed by the results of the investigation comparing the two groups on these measures. More detailed data for each child's individual rate measures can be found in appendices 9 and 10.

4.3.1 Imitated connected speech sample

4.3.1.1 *Articulation rate in the imitated connected speech data*

In tables 4.9 and 4.10 the mean, range, standard deviation (SD) and coefficient of variation (CofV) for the articulation rate measures are shown for both groups of children. The group mean, range, SD and CofV are shown at the bottom of each table.

Articulation rate of the imitated connected speech sample : in segments/s									
	Mean	Range	SD	CofV		Mean	Range	SD	CofV
N1	9.16	8.29-10.87	0.82	9	P1	9.69	6.82-10.80	1.30	13
N2	10.00	9.26-10.48	0.45	5	P2	10.19	6.14-11.87	2.15	21
N3	10.56	9.64-10.94	0.60	6	P3	11.80	8.87-13.94	2.02	17
N4	11.35	9.82-12.29	0.83	7	P4	10.23	8.64-11.49	1.07	10
N5	12.55	10.11-15.85	2.11	17	P5	12.13	9.92-13.58	1.60	13
N6	10.08	10.05-11.97	0.72	6	P6	10.51	8.74-11.46	0.88	8
N7	10.11	9.34-11.57	0.70	7	P7	9.46	5.22-13.75	2.90	31
N8	10.92	10.37-11.64	0.46	4	P8	10.08	8.62-11.65	0.99	10
N9	11.43	9.56-13.61	1.27	11	P9	8.63	7.06-9.75	1.04	12
N10	8.62	7.85-9.40	0.59	7	P10	8.85	6.48-10.38	1.29	10
N11	9.89	7.45-11.15	1.28	13	P11	8.76	7.11-10.24	1.10	13
N12	11.52	7.50-15.38	2.37	21	P12	6.55	4.97-9.14	1.26	15
N13	12.06	9.50-13.64	2.64	22	P13	7.70	6.14-9.27	0.93	12
N14	10.22	8.16-11.30	1.18	12	P14	8.99	5.86-11.64	2.19	24
Group values	**Mean**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean**	**Range of means**	**SD**	**CofV**
	10.68	**8.62-12.55**	**1.14**	**10**		**9.54**	**6.55-12.13**	**1.48**	**15**

Table 4.9 Summary of results for articulation rate in the imitated connected speech sample in segments/s

Articulation rate of the imitated connected speech sample : in syllables/s									
	Mean	Range	SD	CofV		Mean	Range	SD	CofV
N1	3.75	3.24-4.48	0.37	10	P1	4.30	2.92-4.63	0.67	16
N2	4.07	3.61-4.32	0.30	7	P2	4.36	3.29-5.19	0.68	16
N3	4.40	3.97-4.96	0.29	7	P3	5.50	4.34-7.41	0.90	16
N4	4.41	3.82-4.68	0.29	7	P4	4.18	3.60-4.58	0.45	11
N5	4.99	4.05-6.10	0.79	16	P5	4.47	3.82-5.24	0.50	11
N6	4.43	4.02-5.11	0.36	8	P6	4.20	3.35-4.58	0.35	8
N7	4.14	3.74-4.63	0.30	7	P7	3.79	2.50-5.35	0.94	25
N8	4.47	4.27-4.79	0.19	4	P8	3.97	3.70-4.48	0.45	11
N9	4.19	3.37-4.80	0.52	12	P9	3.64	2.94-4.06	0.45	12
N10	3.42	3.14-3.70	0.20	6	P10	3.54	2.59-4.15	0.52	11
N11	4.00	3.44-4.46	0.48	12	P11	3.69	3.05-4.39	0.45	12
N12	4.66	3.00-6.15	0.97	21	P12	2.54	1.99-3.13	0.38	15
N13	4.42	3.45-5.45	0.62	14	P13	3.26	2.73-3.66	0.28	9
N14	4.21	3.26-4.71	0.46	11	P14	3.89	2.20-4.97	0.97	25
Group values	**Mean**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean**	**Range of means**	**SD**	**CofV**
	4.25	**3.42-4.99**	**0.44**	**10**		**3.95**	**2.54-5.50**	**0.57**	**14**

Table 4.10 Summary of results for articulation rate in the imitated connected speech sample in syllables/s

Preliminary inspection of the articulation rate data for the imitated connected speech sample in tables 4.9 and 4.10 above indicates that while the mean articulation rate for the P children is lower than the mean articulation rate for the N children, the mean value for each group lies within the range of individual means for both groups. However, the N children have a smaller range of individual means than the P children. The coefficient of variation indicates that the P children as a group have a wider range of articulation rates than their normally developing peers.

Additionally, two of the P children, P3 and P5, present with much faster imitated articulation rates than the rest of the P children. These rates lie well within the upper end of the range of means for the N children. Inspection of these children's utterances reveal that while P5's utterances are distinct and easily segmented, P3 on the other hand produces utterances with very lax articulation making it difficult to calculate the precise number of syllables produced in the utterances. In figure 4.8 below the difficulty in assigning the individual segment and syllable boundaries in P3's imitated utterances is illustrated, where the utterance is produced without clear distinction between the individual segments. The waveform and transcription in the top window is of P3 saying "two naughty boys picking some bananas" while in the bottom window, for comparison, shows a waveform of P5's utterance "two naughty boys picking some oranges" where the segments are more easily segmented and the syllables more distinguishable.

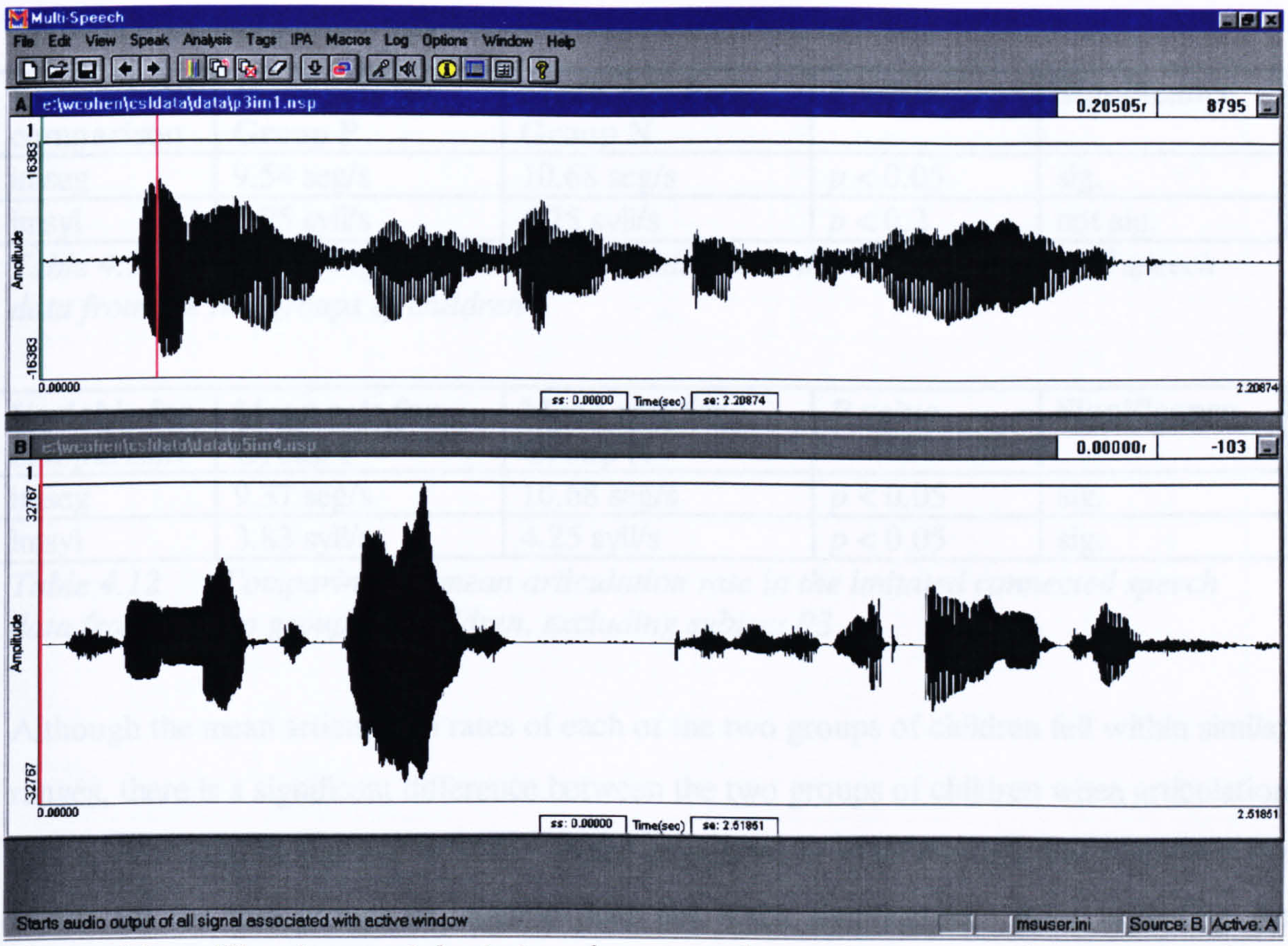

Figure 4.8 Waveforms of the imitated connected speech utterance "two naughty boys picking some bananas" , [ʉ n̪ɔʔɪ b̪ɔɪ iŋ d̪ʌm b̪ɪnanə] *by subject P3 (top) and "two naughty boys picking some oranges"*, [tʉ nɔti bɔɪz pɪtɪŋ sʌm ɔʊənʒəz] *by subject P5 (bottom).*

Evidence of a statistical difference between the mean articulation rates of the two groups of children was explored, taking into consideration P3's data as a potential statistical outlier because of his lax articulation patterns.

4.3.1.2 *Comparing articulation rate in the phonologically disordered and normally developing children's imitated connected speech*

As shown in section 4.2.2, the data comes from a normally distributed population, and is suitable for parametric statistical analysis. To test for the difference between the mean articulation rate for the two groups of children, an independent t-test was used.

The results of this independent t-test on all the imitated connected speech data are shown in table 4.11 below. Table 4.12 shows the results when the t-test was applied to the data excluding the identified outlier, P3.

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
imseg	9.54 seg/s	10.68 seg/s	$p < 0.05$	sig.
imsyl	3.95 syll/s	4.25 syll/s	$p < 0.2$	not sig.

Table 4.11 Comparing the mean articulation rate in the imitated connected speech data from the two groups of children

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
imseg	9.37 seg/s	10.68 seg/s	$p < 0.05$	sig.
imsyl	3.83 syll/s	4.25 syll/s	$p < 0.05$	sig.

Table 4.12 Comparing the mean articulation rate in the imitated connected speech data from the two groups of children, excluding subject P3

Although the mean articulation rates of each of the two groups of children fell within similar ranges, there is a significant difference between the two groups of children when articulation rate is calculated in seg/s ($p < 0.05$). When calculated in syll/s the difference between the means for the two groups of children does not reach significance. After excluding the unusually fast subject P3 from the statistical analysis this difference also reaches significance ($p < 0.05$). Thus, it can be concluded that the P children have significantly slower articulation rates in imitated connected speech than the N children.

Since the children were each instructed to repeat a modelled utterance, which was pre-recorded and thus presented at the same rate for each child, the mean articulation rate of the eight modelled utterances was calculated for comparison with the rates exhibited by the child subjects. The mean rates of the modelled utterances were found to be 10.81 seg/s and 4.45 syll/s.

Additionally, it was noted that the children tended to exhibit simplification processes in their imitated connected speech utterances that were not present in their single word or spontaneous connected speech data. Further analysis of this observation can be found in section 4.5 below.

4.3.2 Spontaneous connected speech sample

4.3.2.1 *Articulation rate in the spontaneous connected speech data*

As for the imitated connected speech sample, the mean, range, standard deviation (SD) and coefficient of variation (CofV) for the articulation rate measures are shown in tables 4.13 and 4.14 for both groups of children. The group mean, range, SD and CofV are shown at the bottom of each table.

Articulation rate of the spontaneous connected speech sample : in segments/s									
	Mean	Range	SD	CofV		Mean	Range	SD	CofV
N1	8.79	6.30-11.29	0.82	9	P1	6.64	5.77-8.09	0.90	14
N2	8.04	6.75-9.84	0.54	7	P2	7.08	6.24-10.18	1.28	18
N3	8.47	5.79-11.60	2.13	25	P3	12.96	7.71-15.43	2.58	20
N4	9.21	4.38-12.47	2.85	31	P4	8.65	2.76-4.86	1.83	21
N5	8.43	4.12-12.94	3.59	43	P5	9.73	8.02-11.78	1.68	17
N6	8.45	6.02-10.95	1.87	22	P6	8.03	4.56-10.74	1.99	25
N7	8.96	5.58-10.75	1.81	20	P7	9.35	7.28-12.31	1.52	16
N8	9.92	6.94-15.15	2.54	26	P8	5.89	4.08-7.50	1.41	24
N9	9.89	7.86-15.66	2.94	30	P9	7.79	7.13-10.00	1.25	16
N10	9.83	7.74-12.06	1.47	15	P10	5.92	5.68-6.16	0.24	24
N11	9.23	7.46-15.81	2.83	31	P11	6.57	5.57-8.03	0.92	14
N12	9.74	8.06-13.68	2.30	24	P12	6.71	5.33-7.98	0.92	4
N13	10.66	7.34-12.91	1.73	16	P13	7.37	5.06-8.78	1.38	19
N14	9.49	7.68-10.93	1.01	11	P14	10.02	5.26-12.57	2.54	25
Group values	**Mean**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean**	**Range of means**	**SD**	**CofV**
	9.22	**8.04-10.66**	**2.03**	**22**		**8.05**	**5.89-12.96**	**1.46**	**18**

Table 4.13 Summary of results for articulation rate in the spontaneous connected speech sample in segments/s

Articulation rate of the spontaneous connected speech sample : in syllables/s									
	Mean	Range	SD	CofV		Mean	Range	SD	CofV
N1	3.37	2.27-3.78	0.82	24	P1	2.85	2.16-3.86	0.57	20
N2	3.25	2.63-4.07	0.54	17	P2	3.14	2.51-4.52	0.62	20
N3	3.34	2.38-5.14	0.62	19	P3	4.66	3.52-6.17	0.95	20
N4	3.77	2.85-5.64	1.19	32	P4	3.74	2.76-4.86	0.70	19
N5	3.30	1.29-6.22	2.19	66	P5	4.01	3.08-4.85	0.50	12
N6	3.36	2.62-4.12	0.49	15	P6	3.28	2.28-4.67	0.89	27
N7	3.59	2.39-4.29	0.60	17	P7	3.47	2.60-4.34	0.50	14
N8	3.74	2.97-6.20	1.03	28	P8	2.94	2.45-3.47	0.42	14
N9	3.82	2.96-5.48	0.80	21	P9	3.37	2.33-4.62	0.79	23
N10	3.69	2.93-3.85	0.87	24	P10	2.39	1.99-2.73	0.37	14
N11	3.59	2.66-6.32	1.24	35	P11	3.15	2.68-4.02	0.56	18
N12	3.79	2.99-6.16	1.34	35	P12	2.94	2.37-2.93	0.45	15
N13	3.87	2.59-4.77	0.69	18	P13	3.22	2.37-4.11	0.64	20
N14	3.89	3.23-4.68	0.48	12	P14	4.36	2.63-5.58	0.88	20
Group values	**Mean**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean**	**Range of means**	**SD**	**CofV**
	3.60	**3.25-3.89**	**0.92**	**26**		**3.39**	**2.39-4.66**	**0.63**	**18**

Table 4.14 Summary of results for articulation rate in the spontaneous connected speech sample in syllables/s

As with the imitated connected speech data, the mean articulation rate for the P children is lower than the mean articulation rate for the N children in the spontaneous connected speech samples. The mean value for the P children does however lie at the lower end of the range of means of the N children. The coefficient of variation of the articulation rate values is similar for both groups of children, with the N children exhibiting greater inter-subject variability than the P children.

Further more, it is once again subject P3 who presents with the fastest articulation rate, again faster than any other child when measured in both seg/s and syll/s. P5's mean articulation rate on the other hand, though within the faster end of the range of means for the P children, is not as fast as for P3. Figure 4.9 below shows an example of one of P3's spontaneous utterances, "look at all the big engines". As with the imitated utterances produced by P3, there is evidence of lax articulation making the segmental and syllabic boundaries difficult to identify.

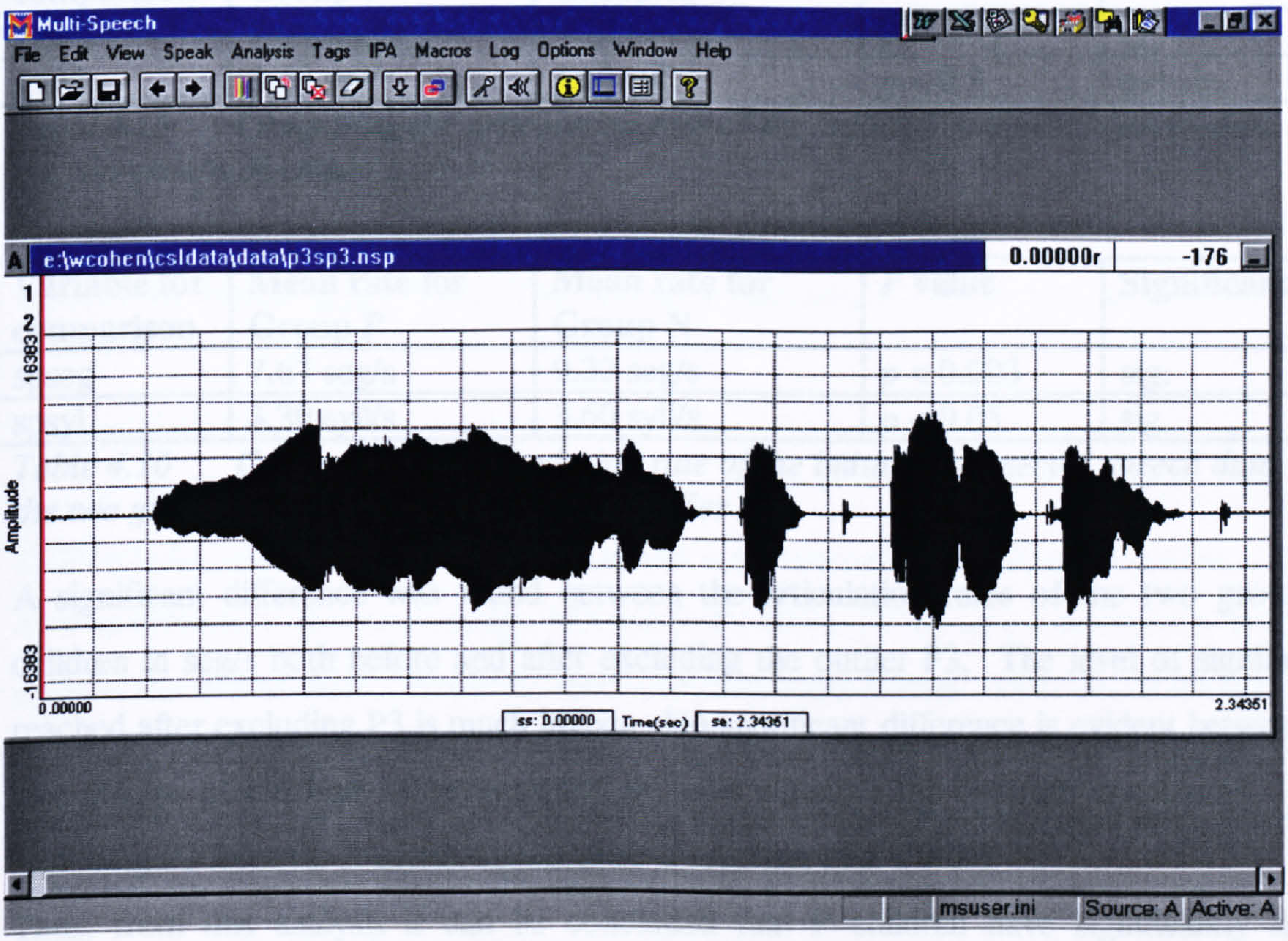

Figure 4.9 Waveform of the spontaneous connected speech utterance "look at all them big engines" [n:ʉl ɔləm b̥ɪg˺ ɛnd̥ənt˺] *by subject P3*

Statistical difference between the mean articulation rates of the two groups of children was tested, taking into consideration the fastest phonologically disordered child's data (P3) as a statistical outlier.

4.3.2.2 *Comparing articulation rate in the phonologically disordered and normally developing children's spontaneous connected speech*

The same statistical procedure was applied to the articulation rates in the spontaneous connected speech data as for the imitated data. The data was shown to come from a normally distributed population (see section 4.2.2 above), and thus suitable for parametric statistical analysis. To test for the difference between the mean articulation rate for the two groups of children, an independent t-test was used.

The results of this independent t-test on all the imitated connected speech data are shown in table 4.15 below. Since subject P3 has been identified as a statistical outlier, the t-test was repeated on the data after excluding this subject's articulation rates. Table 4.16 shows the results when the t-test was applied to the data excluding the identified outlier, P3.

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
spseg	8.05 seg/s	9.22 seg/s	$p < 0.05$	sig.
spsyl	3.39 syll/s	3.60 syll/s	$p < 0.3$	not sig.

Table 4.15 Comparing the articulation rate of the imitated connected speech data in the two groups of children

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
spseg	7.67 seg/s	9.22 seg/s	$p < 0.003$	sig.
spsyl	3.30 syll/s	3.60 syll/s	$p < 0.05$	sig.

Table 4.16 Comparing the articulation rate of the imitated connected speech data in the two groups of children, excluding the outlier P3

A significant difference was found between the articulation rates of the two groups of children in seg/s both before and after excluding the outlier P3. The level of significance reached after excluding P3 is much higher. No significant difference is evident between the two groups of children when measured in syll/s when all the data are considered. After removing P3 from the analysis, significance is reached, at $p < 0.05$.

Thus, from this analysis it can be concluded that P children have significantly slower articulation rates in spontaneous connected speech. This finding is more significant when measured in seg/s than in syll/s.

4.3.3 Summarising the findings of the comparison between the articulation rates of the two groups of children

The P children tended to have slower articulation rates than their normally developing peers. This difference was found to be statistically significant after excluding the identified outlier (the same subject for both samples) for both connected speech samples when measured in both seg/s and syll/s. The significance of the difference between the two groups is greater when measured in seg/s than in syll/s. The implications of these findings are discussed in chapter five, section 5.3.1.

In addition to the comparison between the articulation rates of the two groups of children, the articulation rates of the two connected speech contexts can be compared. All of the N children had faster imitated articulation rate than spontaneous articulation rate when measured in seg/s. One child (N10) had slower imitated articulation rate than spontaneous articulation rate when measured in syll/s while the remaining thirteen were all faster. Eleven P children had faster imitated articulation rate than spontaneous articulation rate when measured in seg/s and twelve when measured in syll/s. Two children, P12 and P14 produced their spontaneous utterances at a faster rate than their imitated utterances, while P3 produced his imitated utterances faster than his spontaneous utterances when measured in seg/s only. This tendency for the imitated articulation rate to be produced faster than spontaneous articulation rate for the majority of children is in contrast to the findings reported by Walker et al (1992). This finding is discussed in chapter five, section 5.2.

4.3.4 DDK rate data

DDK rate for each of the repetition sequences is presented in the following sections. Tables 4.17 to 4.26 show the mean, range, SD and CofV of the DDK rates (measured in syll/s) for each of the monosyllabic, bisyllabic and polysyllabic sequences. Two tables are presented for each sequence, showing the mean DDK rate for all the trials and the mean DDK rate for the trials that were produced accurately. The number of trials produced accurately for each subject is shown in the column headed 'No' and the total number of accurately produced trials produced by the whole group is shown in the group values at the bottom of the table. Group mean, range, SD and CofV are also given.

4.3.4.1 *DDK rates for repetitions of the monosyllable /pə/*

Table 4.17 shows that there is little difference between the two groups of children on the DDK rates for /pə/ of all the trials. The data presented in table 4.18 indicate that a few more N children were able to produce the DDK sequence accurately than P children. The mean DDK rate and the range of mean DDK rates for the two groups of children are similar.

DDK Rate for all attempts of /pə/									
	Mean -syll/s	Range	SD	CofV		Mean-syll/s	Range	SD	CofV
N1	3.72	3.24-4.14	0.35	9	P1	3.45	2.98-3.97	0.40	12
N2	3.96	3.81-4.37	0.25	6	P2	4.18	3.97-4.33	0.17	4
N3	4.82	4.55-5.17	0.24	5	P3	5.26	5.04-5.56	0.23	4
N4	3.96	3.69-4.27	0.26	7	P4	3.60	3.07-4.28	0.53	15
N5	3.48	3.28-3.72	0.18	5	P5	4.11	3.29-4.46	0.47	11
N6	4.37	3.98-4.87	0.39	9	P6	4.08	3.15-4.45	0.93	23
N7	3.60	3.27-3.96	0.27	8	P7	4.50	4.27-4.60	0.14	3
N8	3.78	3.27-3.96	0.72	19	P8	3.93	3.54-4.29	0.27	7
N9	4.01	3.13-4.99	0.46	11	P9	3.78	3.45-4.11	0.26	7
N10	4.33	3.78-4.67	0.35	8	P10	3.71	2.77-4.43	0.65	18
N11	4.29	3.95-4.78	0.32	7	P11	4.11	3.94-4.24	0.11	3
N12	3.96	3.37-4.25	0.36	9	P12	3.08	2.65-3.78	0.43	14
N13	3.93	2.43-4.71	0.91	23	P13	3.24	2.46-3.96	0.62	19
N14	4.16	3.87-4.44	0.23	6	P14	4.01	3.16-4.63	0.66	16
Group values	**Mean -syll/s**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	4.03	**3.48-4.82**	**0.38**	**9**		**3.93**	**3.08-5.26**	**0.42**	**11**

Table 4.17 Summary of DDK rates for all repetitions of /pə/

It is interesting to note that subject P3, whose articulation rates were substantially faster than any other child in the study, was not able to produce the syllable /pə/ accurately. The transcription of his DDK sequences indicate that this child produced all of these syllables with a voiced bilabial stop. The DDK rate for these inaccurate productions (where the voiceless stop was perceived as voiced) at 5.26 syll/s, is much faster than any of the accurate productions produced by any of the other children, suggesting that this child may be attempting to produce speech in a shorter timeframe than his peers with the effect of reducing his articulatory accuracy. From the analysis of this child's speech production abilities shown in appendices 3-5, voicing of bilabial stops was not found to be a feature of this child's speech production system. The implications of these findings and observations are explored in chapter five, section 5.2.

A similar pattern is observed in subject P7, where the /pə/ repetitions were perceived as being produced with a voiced bilabial stop. The DDK rate for these inaccurate productions of 4.50 syll/s, is faster than the accurate DDK rate for the remaining phonologically disordered subjects. For this subject, voicing of bilabial stops was also not found to be a feature of his speech production system. (See appendices 3-5).

DDK Rate for accurate repetitions of /pə/											
	No	**Mean -syll/s**	**Range**	**SD**	**Cof V**		**No**	**Mean-syll/s**	**Range**	**SD**	**Cof V**
N1	5	3.72	3.24-4.14	0.35	9	**P1**	1	2.98	-	-	-
N2	5	3.96	3.73-4.37	0.25	6	**P2**	5	4.18	3.91-4.33	0.17	4
N3	5	4.82	4.55-5.17	0.24	5	**P3**	0	-	-	-	-
N4	5	3.96	3.69-4.27	0.26	7	**P4**	3	3.60	3.07-4.28	0.53	15
N5	5	3.48	3.36-3.72	0.18	5	**P5**	5	4.11	3.29-4.46	0.47	11
N6	4	4.30	3.98-4.87	0.42	10	**P6**	5	4.08	3.15-5.45	0.93	23
N7	4	3.65	3.27-3.96	0.28	8	**P7**	0	-	-	-	-
N8	5	3.78	3.13-4.99	0.72	19	**P8**	5	3.93	3.54-4.29	0.27	7
N9	5	4.01	3.46-4.61	0.46	11	**P9**	5	3.78	3.45-4.11	0.26	7
N10	5	4.33	3.78-4.67	0.35	8	**P10**	2	4.28	4.12-4.43	0.22	5
N11	5	4.29	3.95-4.78	0.32	7	**P11**	5	4.08	3.94-4.24	0.11	3
N12	5	3.96	3.37-4.25	0.36	9	**P12**	5	3.08	2.87-3.78	0.43	14
N13	5	3.30	2.43-4.71	0.91	28	**P13**	4	3.24	2.81-3.96	0.51	16
N14	5	4.16	3.84-4.41	0.23	6	**P14**	5	4.01	3.16-4.63	0.66	16
Group values	**No**	**Mean -syll/s**	**Range of means**	**SD**	**Cof V**	**Group values**	**No**	**Mean-syll/s**	**Range of means**	**SD**	**Cof V**
	68	**3.98**	**3.30-4.82**	**0.35**	**9**		**50**	**3.78**	**2.98-4.28**	**0.54**	**14**

Table 4.18 Summary of DDK rates for accurate repetitions of /pə/

One further observation can be made with regard these findings. Mean DDK rate decreased for both subject group when inaccurate productions are eliminated from the calculations. The implications of this observation are explored in chapter five, section 5.3.4.3.

4.3.4.2 *DDK rates for repetitions of the monosyllable /tə/*

From table 4.19 it is clear that there is little difference between the mean DDK rates for /tə/ of all the trials produced between the two groups of children, with the range of means greater for the P children.

DDK Rate for all attempts of /tə/									
	Mean -syll/s	Range	SD	CofV		Mean-syll/s	Range	SD	CofV
N1	3.67	3.28-4.03	0.32	9	P1	3.75	2.99-4.10	0.44	12
N2	3.99	3.86-4.12	0.11	3	P2	4.90	4.88-5.05	0.11	2
N3	5.05	4.46-5.96	0.58	11	P3	5.13	4.85-5.44	0.22	5
N4	3.85	3.84-3.90	0.05	1	P4	3.24	2.98-3.30	0.28	9
N5	3.54	3.13-3.84	0.26	7	P5	4.30	3.99-4.47	0.19	4
N6	4.70	4.29-5.35	0.41	11	P6	3.98	3.62-4.30	0.25	6
N7	3.62	3.32-3.93	0.25	7	P7	4.39	4.11-4.61	0.18	4
N8	3.53	3.23-4.19	0.39	11	P8	4.07	3.86-4.33	0.17	4
N9	4.15	3.98-4.42	0.16	4	P9	2.98	2.87-3.29	0.18	6
N10	4.06	3.41-5.44	0.86	21	P10	3.92	3.44-4.26	0.35	9
N11	4.40	4.08-4.66	0.23	5	P11	4.30	3.93-4.50	0.24	6
N12	3.37	2.86-3.60	0.31	9	P12	3.24	2.95-3.90	0.43	13
N13	3.47	2.85-4.15	0.47	14	P13	3.24	2.93-4.31	0.60	19
N14	4.54	4.31-4.85	0.20	4	P14	4.52	4.16-4.75	0.32	7
Group values	**Mean -syll/s**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	4.00	**3.37-5.05**	**0.52**	**13**		**3.93**	**2.98-4.90**	**0.57**	**14.5**

Table 4.19 Summary of DDK rates for all repetitions of /tə/

The data presented in table 4.20 indicates however that almost twice as many N children were able to produce the DDK sequence accurately than P children. The mean DDK rate and the range of mean DDK rates for the two groups of children are similar, as is the intra-subject variability, as measured by the coefficient of variation.

Once again, subject P3, whose articulation rates were substantially faster than any other child in the study, was not able to produce the syllable /tə/ accurately. The transcription of his DDK sequences indicate that on the whole this child's productions were perceived as being produced as voiced alveolar stops. The DDK rate for these inaccurate productions at 5.13 syllables/s, is much faster than any of the productions produced by any of the other children. The data indicates that this child achieves a fast rate by sacrificing articulatory accuracy. Voicing of alveolar stops was however a feature of this child's speech production system. (See appendices 3-5).

DDK Rate for accurate repetitions of /tə/											
	No	Mean -syll/s	Range	SD	Cof V		No	Mean-syll/s	Range	SD	Cof V
N1	5	3.67	3.28-4.03	0.32	9	P1	0	-	-	-	-
N2	5	3.99	3.86-4.12	0.11	3	P2	5	4.90	4.74-5.05	0.11	2
N3	5	5.05	4.46-5.96	0.58	11	P3	0	-	-	-	-
N4	5	3.85	3.77-3.90	0.05	1	P4	5	3.24	2.98-3.69	0.28	9
N5	5	3.54	3.13-3.84	0.26	7	P5	2	4.38	4.29-4.47	0.13	3
N6	5	4.70	4.29-5.35	0.41	9	P6	5	3.98	3.62-4.30	0.25	6
N7	5	3.62	3.32-3.93	0.25	7	P7	0	-	-	-	-
N8	5	3.53	3.23-4.19	0.39	11	P8	5	4.07	3.86-4.33	0.17	4
N9	5	4.15	3.98-4.42	0.16	4	P9	4	3.01	2.87-3.29	0.19	6
N10	5	4.06	3.41-5.44	0.86	21	P10	0	-	-	-	-
N11	5	4.40	4.08-4.66	0.23	5	P11	4	4.26	3.93-4.46	0.25	6
N12	5	3.37	2.86-3.60	0.31	9	P12	5	3.24	2.81-3.90	0.43	13
N13	5	3.47	2.85-4.15	0.47	14	P13	2	3.24	2.94-2.99	0.03	1
N14	4	4.46	3.77-4.57	0.11	2	P14	1	4.75	-	-	-
Group values	**No**	**Mean -syll/s**	**Range of means**	**SD**	**Cof V**	**Group values**	**No**	**Mean-syll/s**	**Range of means**	**SD**	**Cof V**
	69	**3.99**	**3.37-5.05**	**0.32**	**8**		**36**	**3.91**	**3.01-4.90**	**0.18**	**5**

Table 4.20 Summary of DDK rates for accurate repetitions of /tə/

4.3.4.3 *DDK rates for repetitions of the monosyllable /kə/*

From table 4.21 it is clear that there is little difference between the mean DDK rates for /kə/ of all the trials produced between the two groups of children. The P children have a higher degree of inter-subject variability, as measured by a greater range of mean DDK rate and by the coefficient of variation.

The data presented in table 4.22 indicates that more than three times as many N children were able to produce the DDK sequence accurately than P children. The mean DDK rate is faster in the N children.

DDK Rate for all attempts of /kə/									
	Mean -syll/s	Range	SD	CofV		Mean-syll/s	Range	SD	CofV
N1	3.22	2.98-3.51	0.22	7	P1	3.21	2.38-3.79	0.53	17
N2	3.62	3.36-3.76	0.18	5	P2	4.74	4.58-4.96	0.15	3
N3	4.17	3.84-4.77	0.38	8	P3	3.96	2.51-4.72	0.85	21
N4	3.43	3.13-3.84	0.27	8	P4	3.67	3.44-6395	0.21	6
N5	3.45	3.23-3.74	0.20	6	P5	3.96	3.62-4.41	0.30	8
N6	4.06	3.62-4.92	0.51	13	P6	3.17	1.97-3.76	0.72	23
N7	4.02	3.76-4.59	0.33	8	P7	4.55	4.14-4.90	0.29	6
N8	3.44	3.07-3.91	0.33	10	P8	4.21	4.16-4.35	0.09	2
N9	3.41	2.62-4.57	0.83	24	P9	2.82	2.52-3.13	0.22	8
N10	3.95	3.66-4.31	0.27	7	P10	3.67	2.99-4.18	0.44	12
N11	4.27	4.02-4.51	0.18	4	P11	4.30	4.10-4.28	0.12	3
N12	4.19	3.87-4.44	0.22	5	P12	2.61	2.21-2.91	0.27	10
N13	3.26	2.93-3.73	0.32	10	P13	2.87	2.24-3.33	0.49	17
N14	3.86	3.79-4.11	0.17	4	P14	3.71	2.36-4.31	0.80	22
Group values	**Mean -syll/s**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	3.74	**3.22-4.27**	**0.37**	**10**		**3.68**	**2.61-4.74**	**0.66**	**18**

Table 4.21 Summary of DDK rates for all repetitions of /kə/

DDK Rate for accurate repetitions of /kə/											
	No	**Mean -syll/s**	**Range**	**SD**	**Cof V**		**No**	**Mean-syll/s**	**Range**	**SD**	**CofV**
N1	5	3.22	2.98-3.51	0.22	0	**P1**	0	-	-	-	-
N2	5	3.62	3.36-3.77	0.18	5	**P2**	0	-	-	-	-
N3	5	4.17	3.84-4.77	0.38	9	**P3**	0	-	-	-	-
N4	5	3.43	3.13-3.84	0.27	8	**P4**	0	-	-	-	-
N5	5	3.45	3.23-3.74	0.20	6	**P5**	0	-	-	-	-
N6	4	3.85	3.62-4.03	0.19	5	**P6**	5	3.17	1.97-3.76	0.72	23
N7	5	4.02	3.90-4.59	0.33	8	**P7**	0	-	-	-	-
N8	5	3.44	3.07-3.91	0.33	10	**P8**	0	-	-	-	-
N9	5	3.41	2.62-3.36	0.83	24	**P9**	3	2.73	2.52-2.90	0.19	7
N10	5	3.95	3.66-4.31	0.27	7	**P10**	5	3.67	2.99-4.18	0.44	12
N11	5	4.27	4.02-4.38	0.18	4	**P11**	0	-	-	-	-
N12	5	4.19	3.87-4.44	0.22	5	**P12**	5	2.61	2.21-2.91	0.27	10
N13	5	3.26	2.93-3.73	0.32	10	**P13**	2	2.87	2.54-3.36	0.58	20
N14	5	3.86	2.61-4.07	0.17	4	**P14**	0	-	-	-	-
Group values	**No**	**Mean -syll/s**	**Range of means**	**SD**	**Cof V**	**Group values**	**No**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	69	**3.72**	**3.22-4.27**	**0.29**	**8**		**20**	**3.01**	**2.61-3.67**	**0.44**	**14**

Table 4.22 Summary of DDK rates for accurate repetitions of /kə/

Once again it is clear that in eliminating the inaccurate repetitions of the DDK sequences, the mean DDK rate for both groups of children is reduced. This is particularly evident in the P children.

4.3.4.4 *DDK rates for repetitions of the bisyllable /pətə/*

In the bisyllabic sequence, there was very little difference between the mean DDK rate for all the trials produced by each group of children, as shown in table 4.23 below. However, fewer disordered children were able to produce the bisyllabic sequence accurately as shown in table 4.24.

DDK Rate for all attempts of /pətə/									
	Mean -syll/s	**Range**	**SD**	**CofV**		**Mean-syll/s**	**Range**	**SD**	**CofV**
N1	3.97	3.45-4.53	0.52	13	**P1**	4.38	3.75-5.00	0.49	11
N2	4.25	3.88-4.56	0.28	7	**P2**	5.03	3.70-5.88	0.90	18
N3	4.74	4.61-4.98	0.16	3	**P3**	5.02	4.83-5.29	0.20	4
N4	4.43	4.01-4.86	0.34	8	**P4**	3.64	2.87-4.49	0.78	21
N5	3.41	2.80-3.99	0.45	13	**P5**	4.60	3.41-6.20	1.22	27
N6	4.58	3.21-5.95	1.14	25	**P6**	4.72	3.91-5.90	0.74	16
N7	4.53	3.21-5.95	0.32	7	**P7**	5.48	5.05-6.09	0.49	3
N8	4.46	4.04-4.76	0.31	7	**P8**	4.27	4.07-4.35	0.20	5
N9	4.85	3.62-6.11	0.90	19	**P9**	3.21	2.91-3.56	0.24	7
N10	4.30	3.72-4.80	0.42	10	**P10**	4.14	3.82-4.63	0.34	8
N11	5.15	4.56-5.60	0.41	8	**P11**	3.88	3.30-4.26	0.38	10
N12	4.15	3.20-6.36	1.26	30	**P12**	3.19	2.93-3.02	0.32	10
N13	4.61	3.89-5.47	0.63	14	**P13**	3.24	2.97-3.62	0.27	8
N14	6.62	5.43-6.93	0.67	10	**P14**	3.69	3.46-3.96	0.25	7
Group values	**Mean -syll/s**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	4.58	**3.97-6.62**	**0.72**	**16**		**4.18**	**3.19-5.48**	**0.74**	**18**

Table 4.23 Summary of DDK rates for all repetitions of /pətə/

In contrast to earlier observations of P3's DDK monosyllabic productions, this child was however able to produce the bisyllabic sequence accurately, with both stop consonants perceived as voiceless. The resultant DDK calculation, though still relatively fast in comparison to a number of P and N children was not however the fastest.

In contrast to the observation of the monosyllabic sequences, the group mean DDK rate of the bisyllabic sequences increases in the P children but not in the N children when inaccurate trials are excluded from the analysis. The implications of this finding are explored in chapter five, section 5.3.4.3.

The P children's group mean DDK rate is slower than the N children's. This is less evident however when the accurate productions are considered only, as shown in table 4.24 below. However, there is considerable overlap between the two groups of children's individual mean DDK rates. Fewer P children were able to produce the sequence accurately however with the highest mean value in the disordered group falling below that of the N children.

DDK Rate for accurate repetitions of /pətə/											
	No	Mean -syll/s	Range	SD	Cof V		No	Mean-syll/s	Range	SD	CofV
N1	5	3.97	3.45-4.53	0.52	13	P1	2	4.38	3.75-5.00	0.88	20
N2	5	4.25	3.88-4.56	0.28	7	P2	5	5.40	3.70-5.88	0.90	17
N3	5	4.74	4.61-4.98	0.16	3	P3	5	5.02	4.83-5.29	0.20	4
N4	5	4.43	4.01-4.86	0.34	8	P4	5	3.64	2.87-4.49	0.78	21
N5	5	3.41	2.80-3.99	0.45	13	P5	4	4.20	3.41-5.43	0.96	23
N6	2	4.09	4.08-4.10	0.01	0	P6	5	4.72	3.91-5.90	0.74	16
N7	5	4.53	4.07-4.89	0.32	7	P7	0	-	-	-	-
N8	5	4.46	4.04-4.76	0.31	7	P8	0	-	-	-	-
N9	4	5.16	4.56-6.11	0.68	13	P9	3	3.10	2.91-3.13	0.18	6
N10	5	4.30	3.72-4.80	0.42	10	P10	0	-	-	-	-
N11	5	5.15	4.56-5.60	0.41	8	P11	0	-	-	-	-
N12	5	4.15	3.20-6.36	1.26	30	P12	0	-	-	-	-
N13	5	4.61	3.89-5.47	0.63	14	P13	0	-	-	-	-
N14	5	6.62	5.10-7.20	0.67	10	P14	0	-	-	-	-
Group values	**No**	**Mean -syll/s**	**Range of means**	**SD**	**Cof V**	**Group values**	**No**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
Group	**66**	**4.56**	**3.97-6.62**	**0.46**	**10**		**29**	**4.35**	**3.64-5.40**	**0.66**	**15**

Table 4.24 Summary of DDK rates for accurate repetitions of /pətə/

4.3.4.5 *DDK rates for repetitions of the polysyllable /pətəkə/*

When DDK rate for /pətəkə/ is calculated from all the trials produced by the two groups of children, it was found that the group mean DDK rate for P children was faster than the group mean DDK rate for the N children as shown in table 4.25 below. Individually, this finding is not observed where there is a degree of overlap between the mean values for both groups of children. There is a greater degree of inter-subject variability, as measured by the coefficient of variation, noted with this faster rate.

However, the trials produced by the P children rarely contained three alternating places of articulation while for approximately half of the N children, they did.

DDK Rate for all attempts of /pətəkə/									
	Mean -syll/s	**Range**	**SD**	**CofV**		**Mean-syll/s**	**Range**	**SD**	**CofV**
N1	3.09	2.55-3.72	0.47	15	**P1**	4.38	3.73-6.31	1.09	25
N2	3.52	3.06-4.07	0.50	14	**P2**	6.14	2.88-7.43	1.85	30
N3	4.02	3.52-4.60	0.50	12	**P3**	3.92	3.38-4.42	0.41	10
N4	3.59	3.09-4.17	0.42	12	**P4**	3.39	3.22-3.75	0.21	6
N5	2.75	2.37-3.25	0.32	12	**P5**	3.84	2.87-4.49	0.70	18
N6	3.12	2.18-4.36	0.84	27	**P6**	5.50	4.26-6.88	1.17	21
N7	4.14	3.65-4.51	0.39	9	**P7**	4.42	3.94-5.51	0.93	21
N8	4.34	3.12-6.71	1.43	33	**P8**	3.67	2.44-4.33	0.76	21
N9	3.32	2.53-4.04	0.58	17	**P9**	2.94	2.65-3.23	0.26	9
N10	3.32	2.97-3.38	0.30	9	**P10**	3.97	3.51-4.31	0.33	9
N11	4.72	3.93-5.63	0.80	17	**P11**	3.73	2.89-4.48	0.75	20
N12	2.71	1.54-3.33	0.73	27	**P12**	2.99	2.44-3.37	0.35	12
N13	3.99	2.99-4.50	0.67	17	**P13**	3.13	2.41-3.84	0.65	21
N14	3.13	2.72-3.54	0.31	10	**P14**	3.77	2.32-4.80	1.10	29
Group values	**Mean -syll/s**	**Range of means**	**SD**	**CofV**	**Group values**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
	3.55	**2.71-4.72**	**0.61**	**17**		**3.98**	**2.94-6.14**	**0.91**	**23**

Table 4.25 Summary of DDK rates for all repetitions of /pətəkə/

The data presented in table 4.26 indicates that while most of the N children were able to produce the DDK sequence accurately (10 out of 14 children) only one P child (P12) was able to produce this sequence alternating three places of articulation, on one occasion only. The transcription of the data indicated this accurate production occurred after three inaccurate productions. While this child was able to produce the three sounds in the correct order on one occasion, sustaining this was not possible for the fifth and final trial of the repetition sequence reflecting the emergence of the skills required to produce the velar target in this child's speech production system.

DDK Rate for accurate repetitions of /pətəkə/											
	No	Mean -syll/s	Range	SD	Cof V		No	Mean-syll/s	Range	SD	CofV
N1	5	3.09	2.55-3.72	0.47	15	P1	0	-	-	-	-
N2	0	-	-	-	-	P2	0	-	-	-	-
N3	5	4.02	3.52-4.60	0.50	12	P3	0	-	-	-	-
N4	5	3.59	3.09-4.17	0.42	12	P4	0	-	-	-	-
N5	0	-	-	-	-	P5	0	-	-	-	-
N6	1	4.36	-	0.00	0	P6	0	-	-	-	-
N7	2	4.37	4.31-4.43	0.08	2	P7	0	-	-	-	-
N8	5	4.34	3.12-6.71	1.43	33	P8	0	-	-	-	-
N9	5	3.32	2.98-4.04	0.58	17	P9	0	-	-	-	-
N10	5	3.32	2.97-3.76	0.30	9	P10	0	-	-	-	-
N11	0	-	-	-	-	P11	0	-	-	-	-
N12	2	2.02	1.54-2.50	0.68	34	P12	1	3.01	-	-	-
N13	0	-	-	-	-	P13	0	-	-	-	-
N14	2	3.23	3.33-3.29	0.02	1	P14	0	-		-	-
Group values	**No**	**Mean -syll/s**	**Range of means**	**SD**	**Cof V**	**Group values**	**No**	**Mean-syll/s**	**Range of means**	**SD**	**CofV**
Group	**37**	**3.57**	**2.02-4.37**	**0.45**	**13**		**1**	**3.01***	**-**	**-**	**-**

* one trial only

Table 4.26 Summary of DDK rates for accurate repetitions of /pətəkə/

4.3.4.6 *Summary*

When inspecting the DDK data the P children as a group do not appear to have DDK rates that are greatly different from the N children as a group, with the exception of the DDK rate for accurate productions of the sequence /kə/. Evidence of any statistically significant difference between the mean DDK rates of the two groups of children is explored in section 4.3.5 below.

Additionally, eliminating the inaccurate productions from the rate calculation affects DDK rate. This finding is discussed in chapter five, sections 5.3.4.3.

The most striking observation that can be made from the DDK data presented in the preceding sections is that of the difficulties most of the P children and some of the N children had in producing the sequences accurately. These difficulties are explored in greater depth in section 4.5 below.

4.3.5 Comparing the P and N children's DDK rates

In the following section the DDK rates for the two groups of children from the all the monosyllabic, bisyllabic and polysyllabic syllable sequences are compared. Rate derived from all attempts at the trials and the accurately produced trials only are compared.

As shown in section 4.2.2, the data comes from a normally distributed population, and is suitable for parametric statistical analysis. To test for the difference between the mean DDK rate for the two groups of children, an independent t-test was used. The results of these analyses are shown in tables 4.27 (all attempts) and 4.28 (accurate productions only).

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
/pə/	3.93 syll/s	4.03 syll/s	$p > 0.05$	not sig.
/tə/	3.93 syll/s	4.00 syll/s	$p > 0.05$	not sig.
/kə/	3.68 syll/s	3.74 syll/s	$p > 0.05$	not sig.
/pətə/	4.18 syll/s	4.58 syll/s	$p > 0.05$	not sig.
/pətəkə/	3.98 syll/s	3.55 syll/s	$p > 0.05$	not sig.

Table 4.27 Results of the comparison of the DDK rates from all trials between the two groups of children

There is very little difference between the DDK rates for each group of children when all the trials are considered. This is reflected in the results of the statistical analysis showing no significant difference between the two groups of children.

Variable for comparison	Mean rate for Group P	Mean rate for Group N	*P* value	Significance
/pə/	3.78 syll/s	3.98 syll/s	$p > 0.05$	not sig.
/tə/	3.91 syll/s	3.99 syll/s	$p > 0.05$	not sig.
/kə/	3.01 syll/s	3.72 syll/s	$p < 0.005$	sig.
/pətə/	4.35 syll/s	4.56 syll/s	$p > 0.05$	not sig.
/pətəkə/	3.01 syll/s *	3.57 syll/s	n/a	-

* This rate is not a mean value, but the rate taken from the only accurately produced /pətəkə/ sequence from the whole of group P.

Table 4.28 Results of the comparison of the accurately produced DDK rates between the two groups of children

In all cases the mean rates of the accurately produced trials for the P children are slightly less than for the N children. This difference was however only found to be statistically significant for the DDK rate of /kə/ where $p < 0.002$. These findings are discussed in chapter five. The fact that a large proportion of the P children were unable to produce the

DDK sequences accurately is of great interest, particularly when the types of errors the children made were considered. These error patterns are explored in section 4.5 below.

4.3.6 Summary of the results of the articulation rate and DDK rate measures

In the preceding sections the various rate measures gathered in the investigation were reported. Comparisons between the two groups of children on each of these rate measures were made using statistical analysis. The findings indicate that the P children (after excluding P3 as a statistical outliers) had significantly slower articulation rates than the N children, both when measured in seg/s and syll/s in both the imitated connected speech sample and the spontaneous connected speech sample.

The comparison of the DDK rate measures revealed that the P children do not have significantly slower DDK rates than the N children when rate is measured on all attempts at the sequences. Similarly, there is no significant difference between DDK rate of the accurately produced trials except for the sequence /kə/, where the P children produced these trials with slower DDK rate than the N children. However, from this analysis it became clear that the P children were less able to produce the DDK sequences accurately than the N children, and the error patterns observed in the DDK productions of the two groups of children is explored in section 4.5 below.

Furthermore, there are methodological implications evident in excluding inaccurate repetitions from an analysis of DDK rate. In the monosyllabic sequences, elimination of inaccurate data led to a decrease in DDK rate, while in the bisyllabic sequences, this led to an increase in DDK rate. This observation is discussed in chapter five, section 5.3.4.3.

Difference between the two groups of children in terms of their phonological skills in these two connected speech tasks are explored in section 4.5 below. There is some indication that greater incidence of simplification processes in the P children's connected speech has implications for the use of the two measures syll/s and seg/s, where the syllable structure of the P children's speech contains fewer segments than the N children. Further exploration of the two rate measures in each of the connected speech contexts follows in section 4.4 below, where the relationship between the two measures is explored. The relationship between measures of articulation rate in the imitated and spontaneous connected speech samples is also explored, along with the relationship between articulation rate and DDK rate.

4.4 The relationship between the various rate measures

Section 4.4.1 describes the results of the analysis investigating the relationship between the measure seg/s and the measure syll/s of the articulation rate in both connected speech samples. Section 4.4.2 describes the results of investigating the relationship between the articulation rate in the imitated connected speech sample and the articulation rate in the spontaneous connected speech sample. The relationship between articulation rate and DDK rate is described in section 4.4.3.

4.4.1 <u>The relationship between the measures syllables/s and segments/s</u>

The results of the analysis investigating the relationship between the measure syll/s and the measure seg/s are presented in the following sections. A strong relationship between the two measures has been demonstrated by Walker <u>et al</u> (1992) in normally developing children and this relationship was further investigated in P children in the reported investigation.

A Pearson's correlation was used to investigate the relationship between the two measures. In this test, a correlation coefficient is calculated to measure the strength of relationship between two variables. The p value of this correlation coefficient determines the strength of significance of this relationship, while the calculation of a 95% confidence interval demonstrates more precisely where the r value lies. In general, an r value of 0.7 or above is deemed to have a strong correlation, while an r value of 0.5 a moderate correlation and an r value of 0.3 or below, a weak correlation.

Scatterplots for each of the correlation analyses were compiled, where the mean articulation rate in seg/s was plotted against the mean articulation rate in syll/s for each child. This shows the strength of the relationship between the two measures where a high articulation rate in seg/s is commensurate with a high articulation rate in syll/s, and vice versa.

4.4.1.1 *The relationship between the measures syll/s and seg/s in the imitated connected speech sample in all the data*

A scatterplot showing the relationship between the two measures for all the subjects is shown in figure 4.10. The line of best fit shows that there is a strong relationship between the measures seg/s and syll/s for the imitated connected speech.

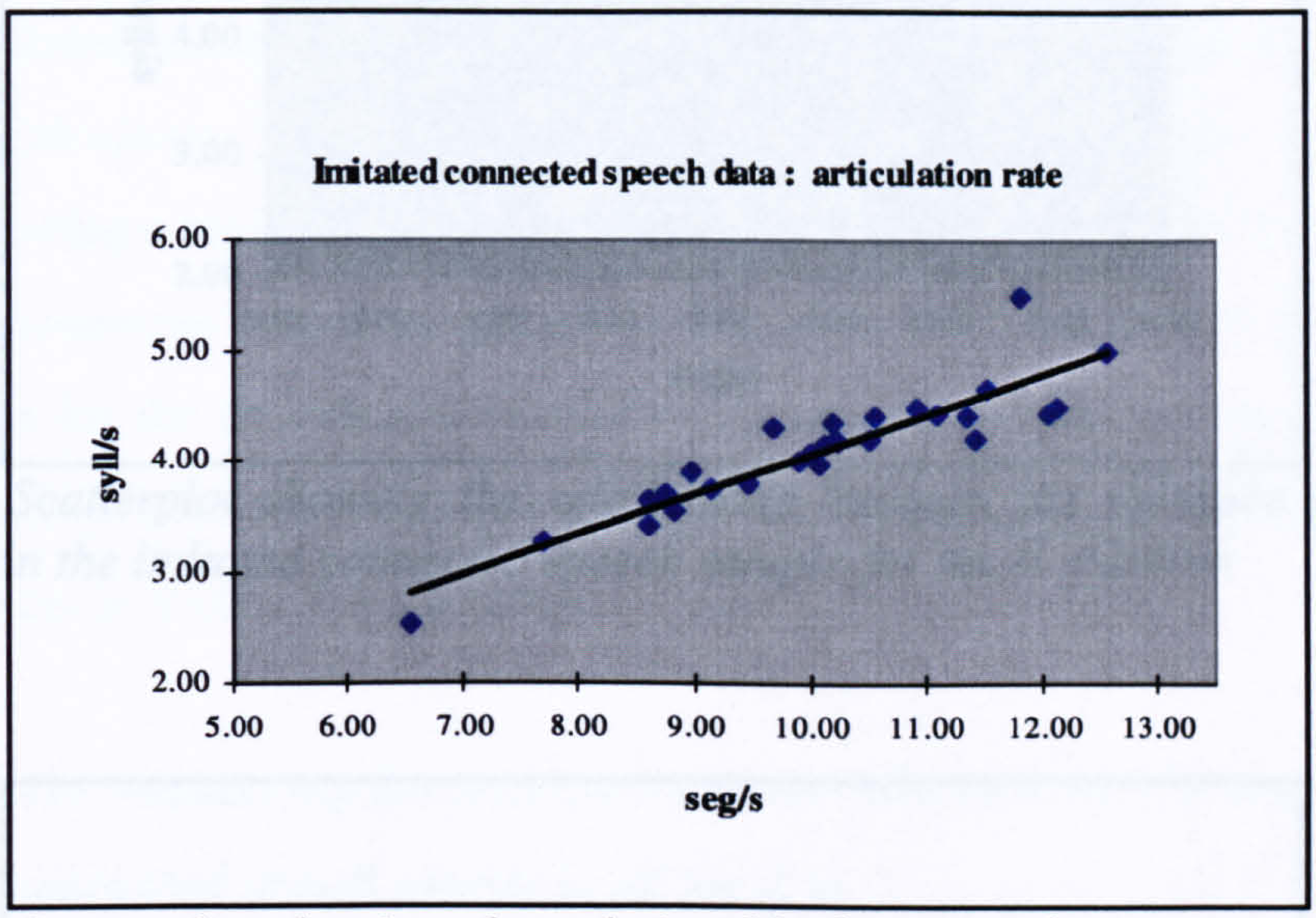

Figure 4.10 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the imitated connected speech sample for all the children

The Pearson's correlation coefficient reveals an r value of 0.91 for the imitated connected speech sample. This coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval supports the strength of this relationship, showing a strong degree of correlation between the measure syll/s and the measure seg/s in the imitated connected speech sample *(95% CI: 0.89, 0.96)*.

4.4.1.2 *The relationship between the measures syll/s and seg/s in the imitated connected speech sample in the N children*

When the N children are considered alone, figure 4.11 shows the relationship between the two measures. In this figure, it is evident that there is a strong relationship between the two measures, with all the children lying close to the line of best fit.

The Pearson's correlation coefficient reveals an r value of 0.92 for the imitated connected speech sample. This correlation coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval supports the strength of this relationship, showing a moderate - strong degree of correlation between the measure syll/s and the measure seg/s in the imitated connected speech sample of the N children *(95% CI: 0.41, 0.97)*.

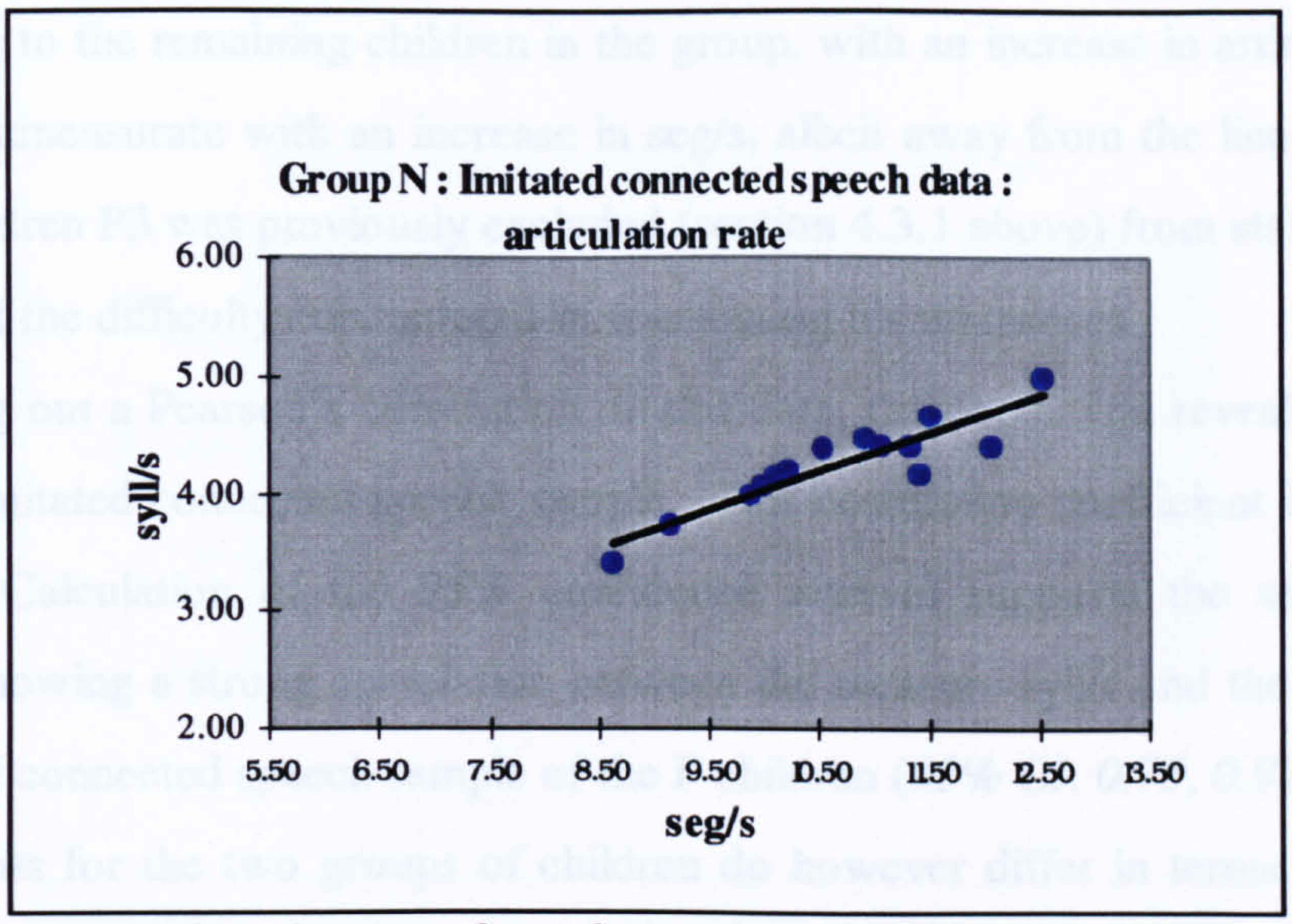

Figure 4.11 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the imitated connected speech sample for the N children

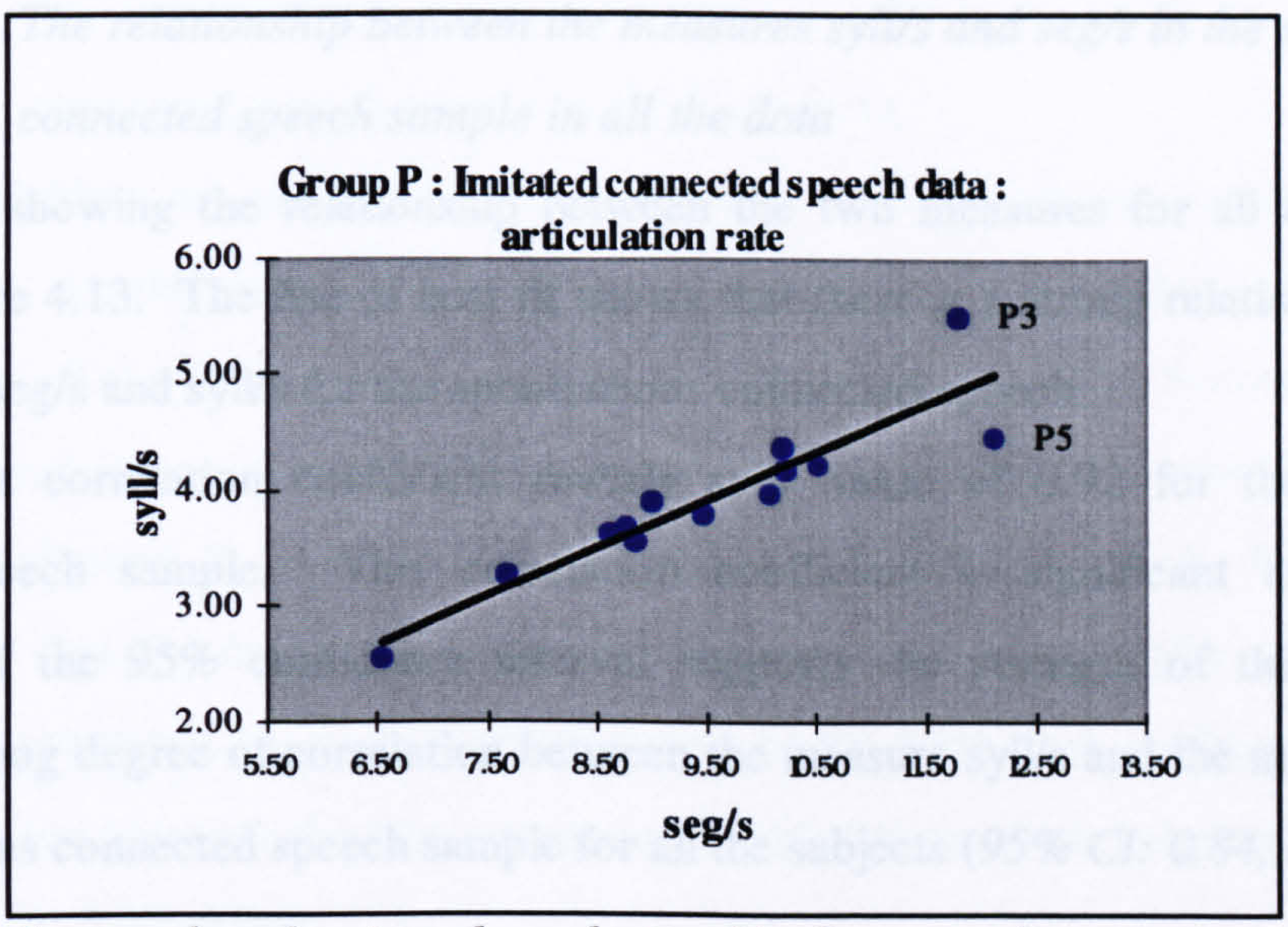

Figure 4.12 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the imitated connected speech sample for the P children

4.4.1.3 *The relationship between the measures syll/s and seg/s in the imitated connected speech sample in the P children*

When the P children are considered alone, figure 4.12 shows the relationship between the two measures. In this figure, it is evident that there is a strong relationship between the two measures, with almost all the children lying close to the line of best fit. The two children identified on the plot, (P3 and P5) were previously identified in section 4.3.1 above as having unusually fast articulation rates. These two children do however present with a similar pattern to the remaining children in the group, with an increase in articulation rate in syllables/s commensurate with an increase in seg/s, albeit away from the line of best fit. Of these two children P3 was previously excluded (section 4.3.1 above) from statistical analysis on the basis of the difficulty encountered in segmenting his utterances.

When carrying out a Pearson's correlation on this data, the coefficient reveals an r value of 0.92 for the imitated connected speech sample. This correlation coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval supports the strength of this relationship showing a strong correlation between the measure syll/s and the measure seg/s in the imitated connected speech sample of the P children (*95% CI: 0.75, 0.97*).

The scatterplots for the two groups of children do however differ in terms of the relative scatter of the values, with the P children having a wider spread of values. This observation is explored further in section 4.4.1.8 below.

4.4.1.4 *The relationship between the measures syll/s and seg/s in the spontaneous connected speech sample in all the data*

A scatterplot showing the relationship between the two measures for all the subjects is shown in figure 4.13. The line of best fit shows that there is a strong relationship between the measures seg/s and syll/s for the spontaneous connected speech.

The Pearson's correlation coefficient reveals an r value of 0.92 for the spontaneous connected speech sample. This correlation coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval supports the strength of this relationship, showing a strong degree of correlation between the measure syll/s and the measure seg/s in the spontaneous connected speech sample for all the subjects (*95% CI: 0.84, 0.99*).

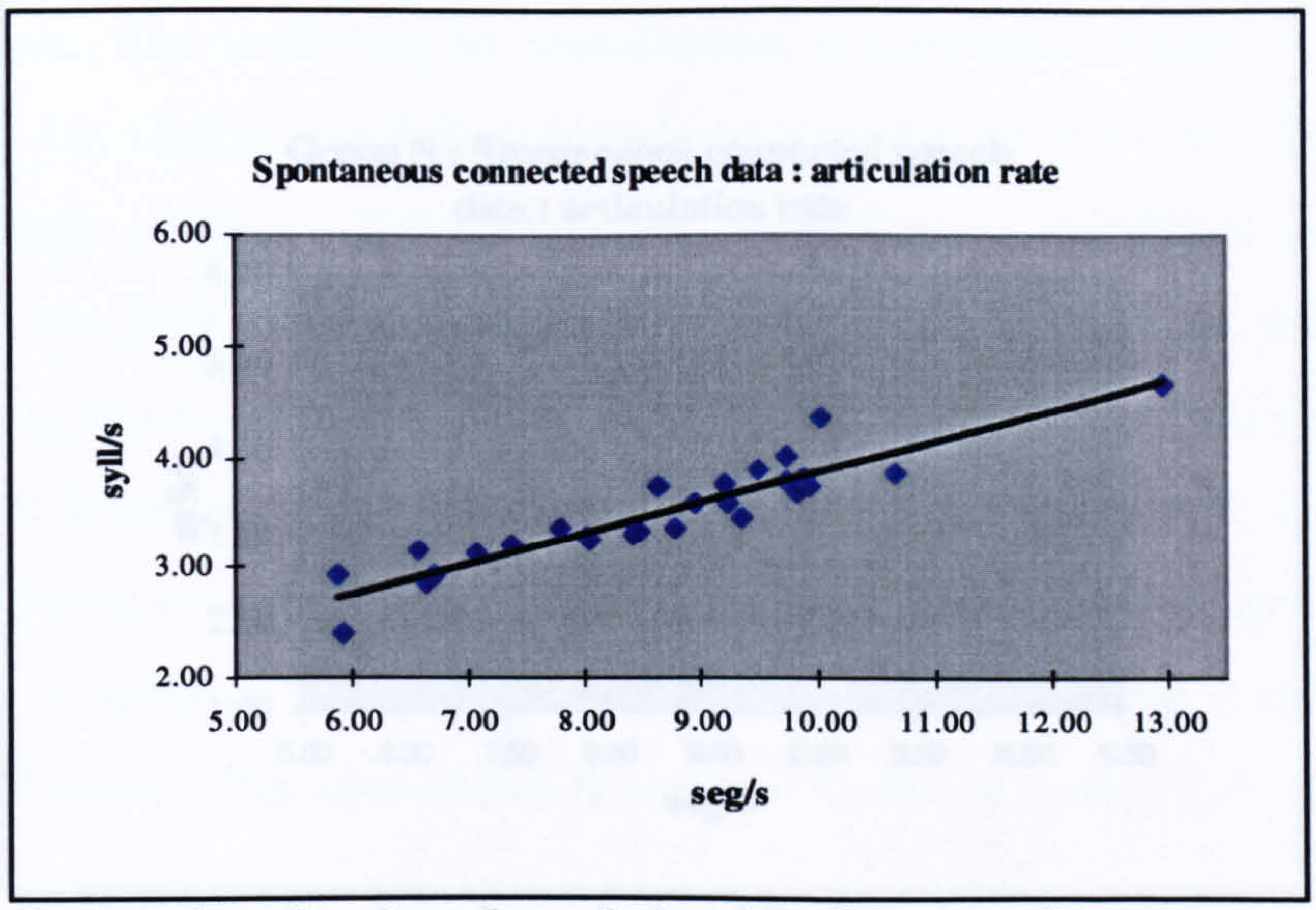

Figure 4.13 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the spontaneous connected speech sample for all the children

4.4.1.5 *The relationship between the measures syll/s and seg/s in the spontaneous connected speech sample in the N children*

When the N children are considered alone, figure 4.14 shows the relationship between the two measures. In this graph, it is evident that there is a relationship between the two measures, with all the children lying close to the line of best fit. The Pearson's correlation coefficient reveals an *r* value of 0.83 for the spontaneous connected speech sample. This correlation coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval shows that the degree of correlation between the measure syll/s and the measure seg/s in the spontaneous connected speech sample of the N children confirms the moderate-strong correlation between the two measures of articulation rate in spontaneous connected speech (*95% CI: 0.53, 0.94*).

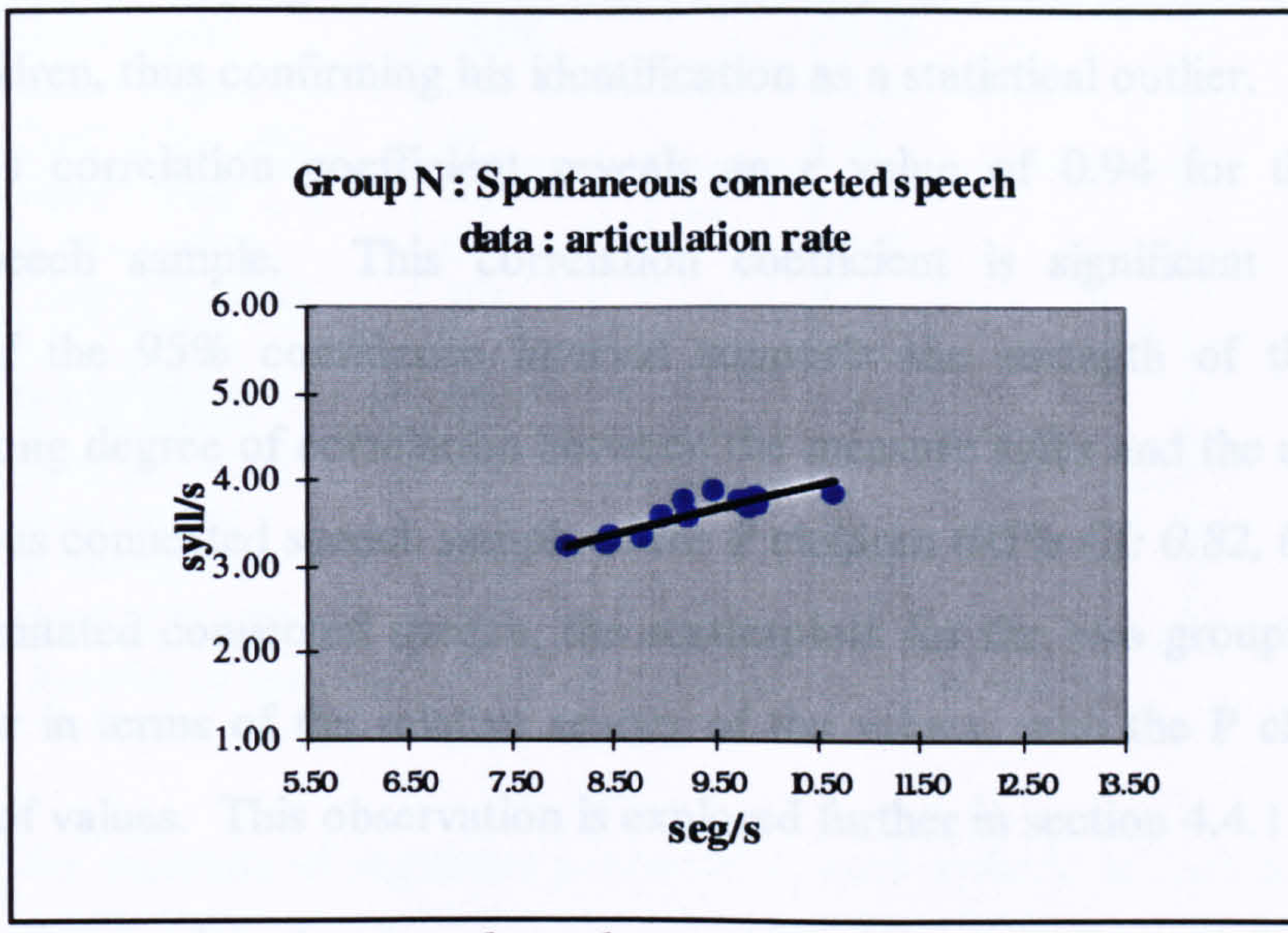

Figure 4.14 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the spontaneous connected speech sample for the N children

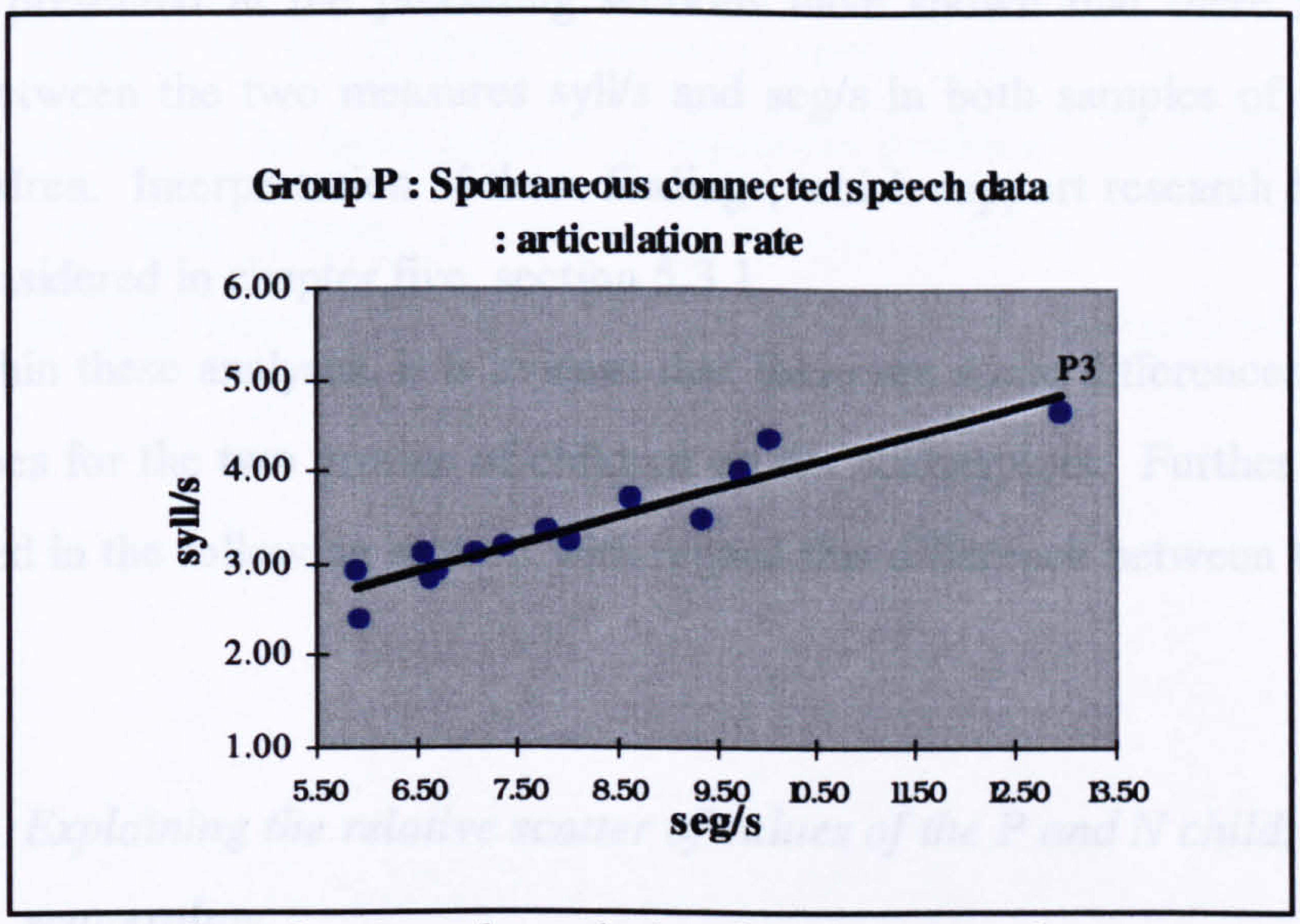

Figure 4.15 Scatterplot showing the relationship between the measure syll/s and the measure seg/s in the imitated connected speech sample for the P children

4.4.1.6 *The relationship between the measures syll/s and seg/s in the spontaneous connected speech sample in the P children*

When the P children are considered alone, figure 4.15 above shows the relationship between the two measures. In this graph, it is evident that there is a relationship between the two measures, with all the children lying close to the line of best fit. In section 4.3.2 above, child P3 was identified as an outlier in terms of having an unusually fast articulation rate in comparison to the other P children. This child is identified on the plot above, and it is clear that while there is a relationship between the measures seg/s and syll/s in his speech data (evidenced by the mark lying close to the line of best fit) the point is some distance from the remaining children, thus confirming his identification as a statistical outlier.

The Pearson's correlation coefficient reveals an *r* value of 0.94 for the spontaneous connected speech sample. This correlation coefficient is significant at $p < 0.001$. Calculation of the 95% confidence interval supports the strength of this relationship, showing a strong degree of correlation between the measure syll/s and the measure seg/s in the spontaneous connected speech sample of the P children *(95% CI: 0.82, 0.98).*

As with the imitated connected speech, the scatterplots for the two groups of children do however differ in terms of the relative scatter of the values, with the P children having a wider spread of values. This observation is explored further in section 4.4.1.8 below.

4.4.1.7 *Summary*

The analyses presented in the preceding sections have shown that there is a significant relationship between the two measures syll/s and seg/s in both samples of speech in both groups of children. Interpretation of these findings, which support research by Walker et al (1992) are considered in chapter five, section 5.3.1.

However, within these analyses, it is evident that there are some differences in the relative spread of values for the two groups of children on the scatterplots. Further analysis of the data is reported in the following section with regard this difference between the two groups of children.

4.4.1.8 *Explaining the relative scatter of values of the P and N children's scatterplots*

One of the most striking features of the scatterplots presented in the preceding sections is the difference in the relative scatter of values of the P and N children. The difference between the spread of values may be a reflection of differences in the inter-subject variability of the two groups of children. Calculation of the group coefficient of variation, shown in table 4.29 below, reveals that the P children as a group present with greater inter-subject variability in articulation rate measures in both seg/s and syll/s in the imitated connected speech while the reverse is found for the spontaneous connected speech data, where the N children present with greater inter-subject variability. Thus differences in inter-subject variability of the two groups of children do not account for the spread of values observed.

Variable	Measure	Group N	Group P
imseg	Mean (seg/s)	10.68	9.54
	St Dev (seg/s)	1.14	1.48
	Coeff of Var (%)	10	15
imsyl	Mean (syll/s)	4.25	3.95
	St Dev (syll/s)	0.44	0.57
	Coeff of Var (%)	10	14
spseg	Mean (seg/s)	9.22	8.05
	St Dev (seg/s)	2.03	1.46
	Coeff of Var (%)	22	18
spsyl	Mean (syll/s)	3.60	3.39
	St Dev (syll/s)	0.92	0.63
	Coeff of Var (%)	26	18

Table 4.29 Results of the analysis of the coefficient of variation

An analysis of the numbers of segments produced in each syllable in each group of children reveals two interesting results. Firstly, the P children produce syllables made up of fewer segments, and as such fewer articulatory gestures. Secondly, there are fewer segments produced per syllable in the imitated connected speech data than in the spontaneous connected speech data. The mean number of segments produced per syllable by each child was calculated for both samples of connected speech. The results of this analysis are presented in table 4.30 below. The implications of this finding are discussed in chapter five, section 5.3.1.

Subject	Imitated Speech	Spontaneous Speech	Subject	Imitated Speech	Spontaneous Speech
	segments/ syllable	segments/ syllable		segments/ syllable	segments/ syllable
N1	2.3	2.6	P1	2.1	2.6
N2	2.3	2.6	P2	2.5	2.5
N3	2.3	2.6	P3	2.2	2.8
N4	2.6	2.6	P4	1.6	2.4
N5	2.3	2.9	P5	2.3	2.6
N6	2.3	3.0	P6	2.3	2.6
N7	2.3	2.7	P7	2.1	2.5
N8	2.3	2.7	P8	2.1	2
N9	2.1	2.6	P9	2.2	2.5
N10	2.4	2.8	P10	2.3	2.3
N11	2.4	2.7	P11	2.2	2.4
N12	2.3	2.8	P12	2.2	2.2
N13	2.4	2.8	P13	2.2	2.4
N14	2.3	2.5	P14	2.1	2.3
Group Mean	2.3	2.7	Group Mean	2.2	2.4

Table 4.30 Mean numbers of segments produced per syllable for each subject in each connected speech type. Group values are also shown.

An independent t-test was carried out on this data, showing that the P children had significantly fewer segments per syllable than the N children in both the imitated and spontaneous connected speech samples. This was statistically significant at $p < 0.05$ for the imitated data and $p < 0.01$ for the spontaneous data.

Thus the difference between the two groups in terms of the number of segments produced per syllable may explain the greater spread of values for the P children in the scatterplots above, and not the inter-subject variability. The N children's syllabic structure is more like the adult form than the P children.

The same statistical analysis was applied to determine whether the imitated data produced by the children contained fewer segments/syllable than the spontaneous data. The results of this analysis are shown in table 4.31 below, where it is clear that there is a statistically significant difference between the two speech data sets where the imitated utterances for both groups of children contain fewer segments/syllable than the spontaneous utterances.

	Group N				Group P			
	Mean segs/syll in spont data	**Mean segs/syll in imit data**	***P* value**	**Sig.**	**Mean segs/syll in spont data**	**Mean segs/syll in imit data**	***P* value**	**Sig.**
imitated vs spont.	2.7	2.3	$p <$ 0.005	S	2.4	2.2	$p <$ 0.005	S

Table 4.31 Results of the comparison of the number of segments produced per syllable in the two connected speech types

While there appears to be little difference between which of the two measures seg/s and syll/s should be used to calculate articulation rate this finding does indicate the preference of the use of seg/s as a more accurate measure. Where the P children reduced syllable structure and the N children less so, comparing the articulation rate of the two different connected speech samples in syll/s does not strictly speaking compare like with like. For this reason, the comparison of the articulation rates of the two samples of speech in the following section uses the seg/s measure only.

4.4.2 <u>The relationship between the articulation rate of the imitated and spontaneous connected speech samples</u>

The results of the analysis investigating the relationship between the articulation rate of the imitated and spontaneous connected speech samples are presented in the following sections. Despite the endeavours of the investigator to measure connected speech utterances of similar lengths, it was reported in section 4.2.3 above that the spontaneous utterances produced by both groups of children were slightly longer than the imitated utterances, and interpretation of the analysis presented in the following section must therefore be made with care.

A Pearson's correlation was used to investigate the relationship between the seg/s measures of the imitated and spontaneous speech samples. The data from all the children and the data from the two individual groups were each considered.

As with the previous analysis, scatterplots were drawn for each of the correlation analyses in the following sections. The mean imitated articulation rate value for each child in seg/s was plotted against the mean spontaneous articulation rate value in seg/s for the same child. Thus the extent to which high articulation rate in imitated connected speech is associated with high articulation rate in spontaneous connected speech can be investigated.

4.4.2.1 *Findings relating to all the data*

A scatterplot showing the relationship between the seg/s measure for the imitated and spontaneous connected speech samples is shown in figure 4.16. From this figure, it is evident that the relationship between the measure in the two connected speech samples is weak, with most of the children lying away from the line of best fit.

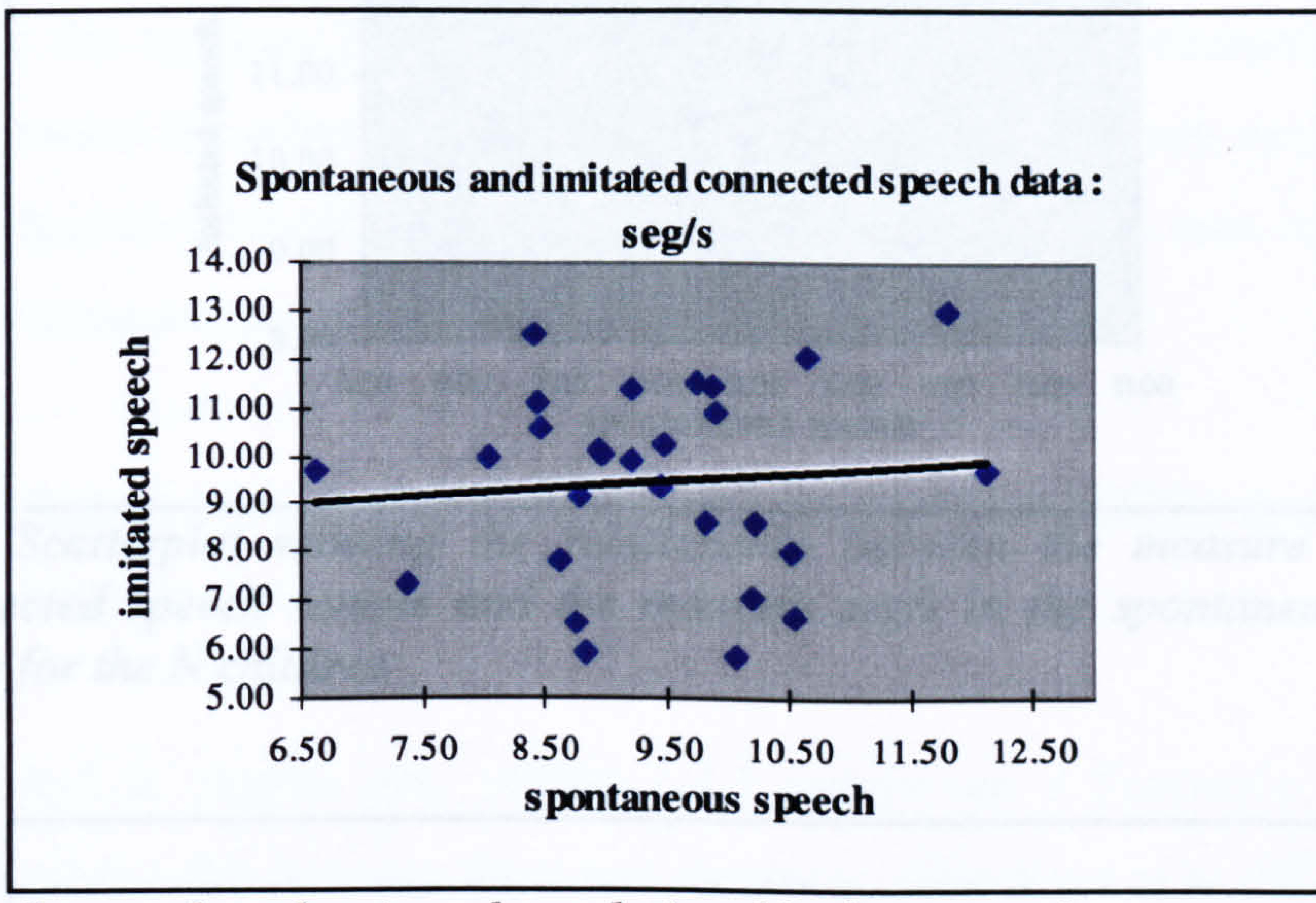

Figure 4.16 Scatterplot showing the relationship between the measure seg/s in the imitated connected speech sample and the measure seg/s in the spontaneous connected speech sample for all the children

The Pearson's correlation coefficient echoes this, where the *r* value of 0.55 is considered to be a moderate correlation. The 95% confidence interval of 0.24, 0.74 suggests the correlation is weak.

4.4.2.2 *Findings relating to the N children*

When the N children are considered alone, figure 4.17 shows the relationship between the seg/s measure for the imitated and spontaneous connected speech samples. From this figure, it is evident that the relationship between the measure in the two connected speech samples is weak, with few children lying on or near the line of best fit.

The Pearson's correlation coefficient reveals an *r* value of 0.20. This is considered a weak correlation, and the 95% Confidence interval of -0.37, 0.74 confirms that the two measures are not comparable.

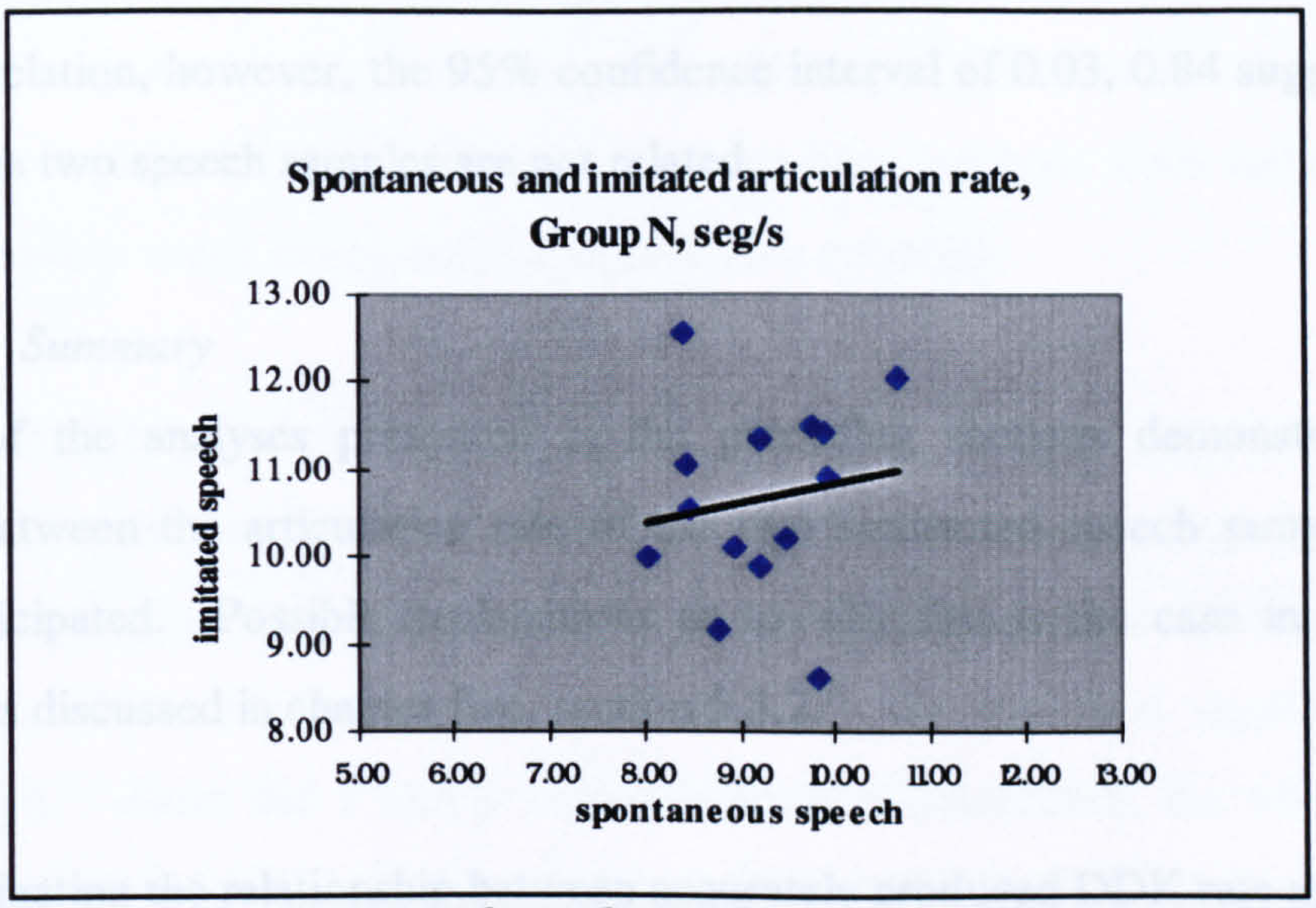

Figure 4.17 Scatterplot showing the relationship between the measure seg/s in the imitated connected speech sample and the measure seg/s in the spontaneous connected speech sample for the N children

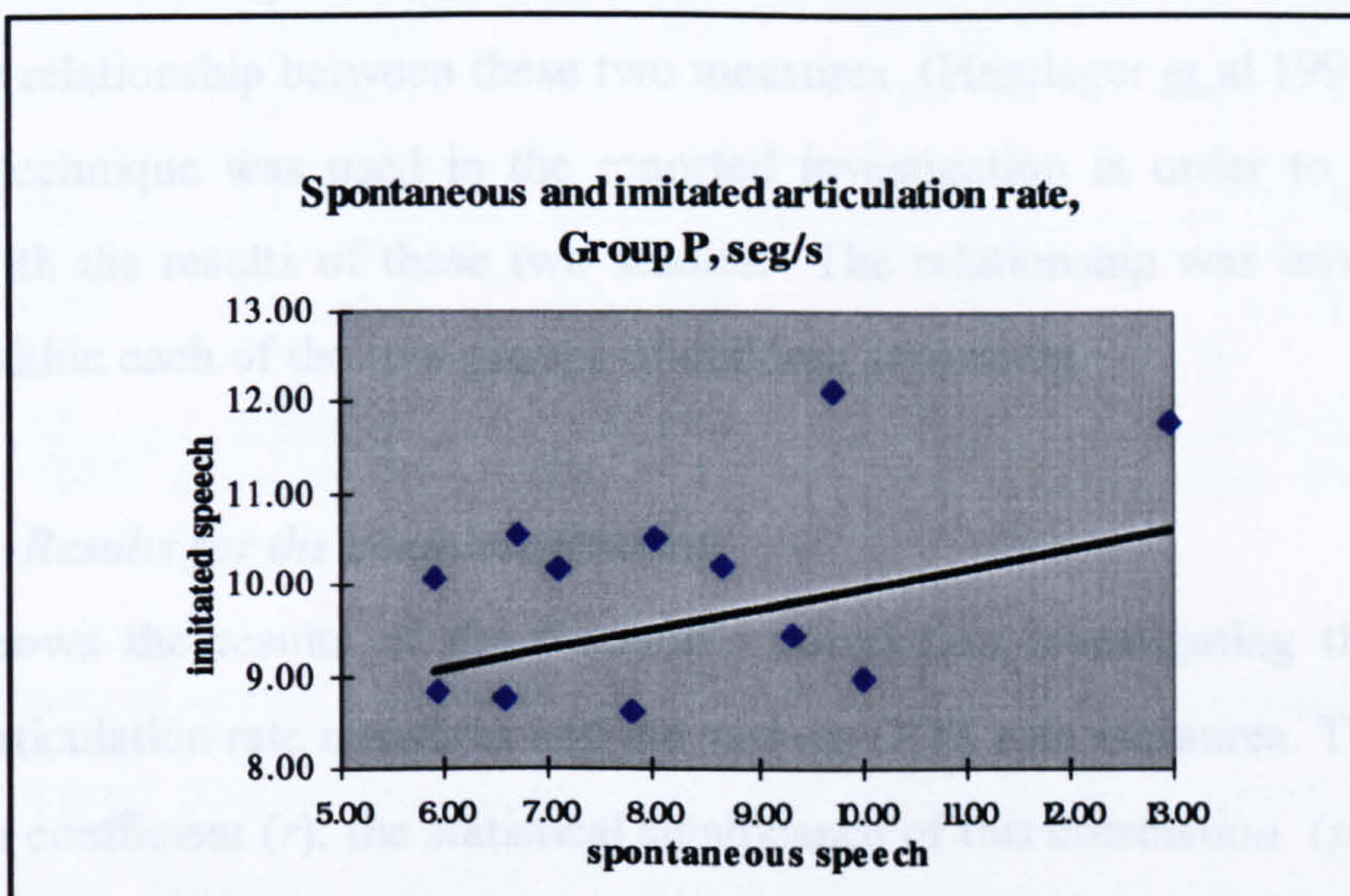

Figure 4.18 Scatterplot showing the relationship between the measure seg/s in the imitated connected speech sample and the measure seg/s in the spontaneous connected speech sample for the P children

4.4.2.3 *Findings relating to the P children*

When the P children are considered alone, figure 4.18 shows the relationship between the seg/s measure for the imitated and spontaneous connected speech samples. From this figure, it is evident that the relationship between the measure in the two connected speech samples is weak, with few children lying close to the line of best fit.

The Pearson's correlation coefficient reveals an *r* value of 0.55. This could be considered a moderate correlation, however, the 95% confidence interval of 0.03, 0.84 suggests that the measures in the two speech samples are not related.

4.4.2.4 *Summary*

The results of the analyses presented in the preceding sections demonstrate that the relationship between the articulation rate of the two connected speech samples is not as strong as anticipated. Possible explanations as to why this is the case in the reported investigation is discussed in chapter five, section 5.3.2.

4.4.3 Investigating the relationship between accurately produced DDK rate and articulation rate

Two studies cited in chapter one, section 1.4.3 carried out a Pearson's correlation to investigate the relationship between these two measures (Haselager et al 1991, Yaruss et al 1994). This technique was used in the reported investigation in order to make a direct comparison with the results of these two studies. The relationship was investigated in all the data and within each of the two groups of children separately.

4.4.3.1 *Results for the complete dataset*

Table 4.32 shows the results of the Pearson's correlation investigating the relationship between the articulation rate measures and the various DDK rate measures. The table shows the correlation coefficient (*r*), the statistical significance of this correlation (*p*), where the *r* and *p* values indicate a correlation, the 95% confidence interval (*CI*) has been calculated, and whether or not the result is significant (sig./not sig.) Those relationships that have been identified as having some relation are highlighted in bold.

	/pə/	/tə/	/kə/	/pətə/	/pətəkə/
imsyl	r = 0.21 p = 0.3 not sig.	r = 0.26 p = 0.22 not sig.	**r = 0.49 p = 0.03 CI: -0.08, 0.87 sig.**	r = 0.11 p = 0.60 not sig.	r = 0.19 p = 0.57 not sig.
spsyll	r = 0.14 p = 0.49 not sig.	r = 0.12 p = 0.57 not sig.	r = 0.29 p = 0.23 not sig.	r = 0.26 p = 0.26 not sig.	r = -0.13 p = 0.71 not sig.

Table 4.32 Table showing the results of the Pearson's correlation investigating the relationship between articulation rate and DDK rate for all the children

When the analysis is carried out on the complete cohort of data, some relationship is revealed between imitated articulation rate (in syll/s) and DDK rate for the monosyllable /kə/. However, the 95% CI, which shows the *r* value lying between -0.08 and 0.87, reveals that this relationship is not strong and the significance doubtful.

4.4.3.2 *Results for the N children*

Table 4.33 shows the results of the Pearson's correlation investigating the relationship between the articulation rate measures and the various DDK rate measures in the N children only. The table shows the correlation coefficient (*r*), the statistical significance of this correlation (*p*), where the *r* and *p* values indicate a correlation, the 95% confidence interval (*CI*) has been calculated, and whether or not the result is significant (sig./not sig.) Those relationships that have been identified as having some relation are highlighted in bold.

	/pə/	/tə/	/kə/	/pətə/	/pətəkə/
imsyl	r = -0.28 p = 0.32 not sig.	r = -0.19 p = 0.50 not sig.	r = -0.10 p = 0.73 not sig.	r = -0.22 p = 0.45 not sig.	r = -0.05 p = 0.88 not sig.
spsyll	r = -0.18 p = 0.55 not sig.	r = -0.27 p = 0.36 not sig.	r = -0.05 p = 0.86 not sig.	**r = 0.56** **p = 0.03** **CI: 0.12, 0.74** **sig.**	r = -0.416 p = 0.25 not sig.

Table 4.33 Table showing the results of the Pearson's correlation investigating the relationship between articulation rate and DDK rate the N children

When the analysis is carried out on the N children's data, some relationship is revealed between spontaneous articulation rate (in syll/s) and DDK rate for accurate productions of the bisyllable /pətə/. However, the 95% CI, which shows the *r* value lying between 0.12 and 0.74, reveals that this relationship is not strong and the significance doubtful.

4.4.3.3 *Results for the P children*

Table 4.34 shows the results of the Pearson's correlation investigating the relationship between the articulation rate measures and the various DDK rate measures in the P children only. The table shows the correlation coefficient (*r*), the statistical significance of this correlation (*p*), where the *r* and *p* values indicate a correlation, the 95% confidence interval (*CI*) has been calculated, and whether or not the result is significant (sig./not sig.) Those relationships that have been identified as having some relation are highlighted in bold.

	/pə/	/tə/	/kə/	/pətə/	/pətəkə/
imsyl	r = 0.42 p = 0.17 not sig.	**r = 0.58** **p = 0.08** **CI: 0.04, 0.84** **sig.**	r = 0.50 p = 0.39 not sig.	r = 0.64 p = 0.12 not sig.	n/a **
spsyll	r = 0.16 p = 0.62 not sig.	r = 0.31 p = 0.39 not sig.	r = -0.69 p = 0.19 not sig.	r = 0.07 p = 0.88 . not sig.	n/a **

** There is not enough data (i.e. only one subject was able to produce one accurate repetition of /pətəkə/ so the correlation is not viable).

Table 4.34 Table showing the results of the Pearson's correlation investigating the relationship between articulation rate and DDK rate the P children

When the analysis is carried out on the P children's data, some relationship is revealed between imitated articulation rate (in syll/s) and DDK rate for accurate productions of the monosyllable /tə/. However, the 95% CI, which shows the *r* value lying between 0.04 and 0.84, reveals that this relationship is not strong and the significance doubtful.

4.4.3.4 *Summary*

No significant relationship has been observed between rate of articulation when measured as articulation rate, and maximum performance production, when measured as DDK rate. That is, the subjects who are fastest on one measure are not necessarily the fastest on another. These results are discussed in chapter five, section 5.3.3.

4.5 Error analysis of the connected speech and DDK productions

As pointed out earlier in section 4.1, both the N and P children present with a number of simplification processes in their single word and connected speech data. The P children present with a far greater proportion of these processes, distinguishing them from the N children on this basis. These simplification processes, both systemic and structural in nature, occur in the single word, connected speech and DDK data. Simplification processes are defined in phonological theory, and as such represent the error patterns children produce when acquiring the adult sound system as a series of rules governing speech sound production stemming from linguistic theory. Thus, when a child uses a simplification process, the rule governing the errored production indicates that it should be present in all speech contexts. However, in the following sections, the imitated connected speech data and the DDK data are explored showing evidence of additional error patterns that are supplementary to those observed in the single word and spontaneous connected speech patterns, where a simplification process is present in one or two speech contexts but not elsewhere. Error patterns in the imitated connected speech task and the DDK tasks are explored in sections 4.5.1 - 4.5.4 below. In section 4.5.5, those children with error patterns in both the imitated task and the DDK task are considered in terms of their underlying speech motor skills.

4.5.1 Error patterns in the imitated connected speech utterances that are supplementary to those simplification processes observed in the single word and spontaneous connected speech utterances

An analysis of each child's speech production in terms of the simplification processes present was carried out on each of the three speech contexts: single word, imitated connected and spontaneous connected. Details of this analysis for each of the children can be found in appendix 5. Two N children and eleven P children exhibit at least one simplification process in their imitated connected speech utterances that they do not exhibit in either their single word productions or in their spontaneous connected speech utterances. Table 4.35 below shows these children and the "extra" simplification process they use in their imitated connected utterances. P7 is the only subject who presents with a process in both contexts. However, the stopping of fricatives evident in his imitated connected speech data refers to stopping of /f/ → /p/. In the single word and spontaneous connected speech contexts he does not stop /f/ → /p/. These findings are discussed in chapter five, section 5.2.

Subject	Simplification process
N7	stopping of fricatives
N12	context sensitive voicing
P1	backing of alveolar stops
P2	context sensitive voicing final consonant deletion
P3	final consonant deletion
P4	final consonant deletion
P5	word final devoicing
P7	stopping of fricatives
P8	backing of alveolar stops context sensitive voicing
P9	final consonant deletion
P10	final consonant deletion
P11	liquid / glide simplification final consonant deletion
P14	context sensitive voicing

Table 4.35 Simplification processes used by some of the N and P children in their imitated connected speech utterances that are not present in their single word or spontaneous connected speech utterances.

4.5.2 Error analysis of the monosyllabic DDK tasks

As described in section 4.2.6 the P children produced fewer accurate productions of the DDK syllable sequences than N children.

In the monosyllabic DDK sequences three error categories were identified: correct production (correct); an error that is predictable on the basis of single word and connected speech patterns (predictable); and an error that is not predictable on the basis of single word and connected speech patterns (non-predictable). Figures 4.19 to 4.46 below show the results of this analysis for the N and P children. Correct productions are shown in dark blue, predictable errors in light blue and non-predictable errors in red.

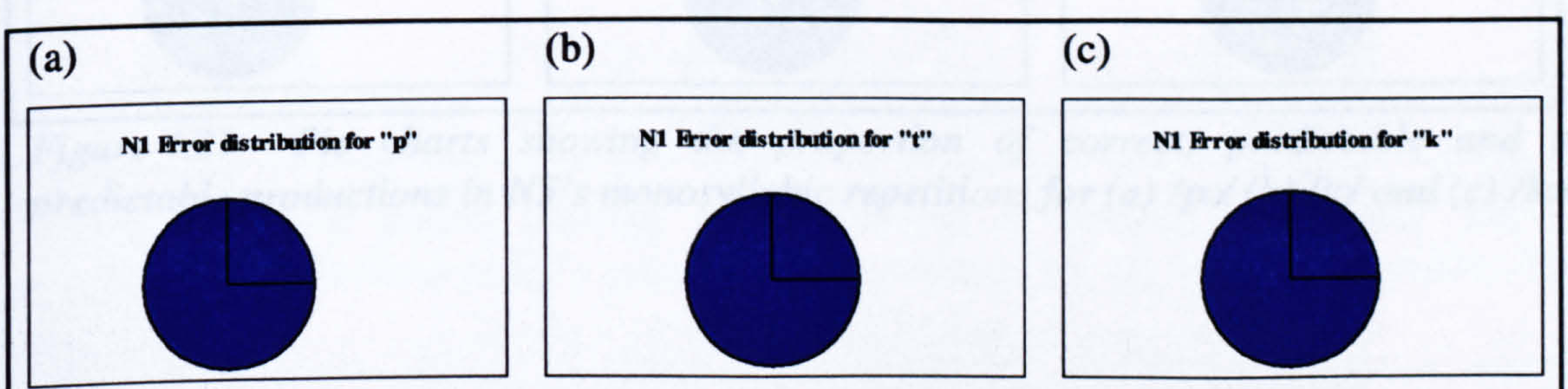

Figure 4.19 Pie charts showing the proportion of correct, predictable and non-predictable productions in N1's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

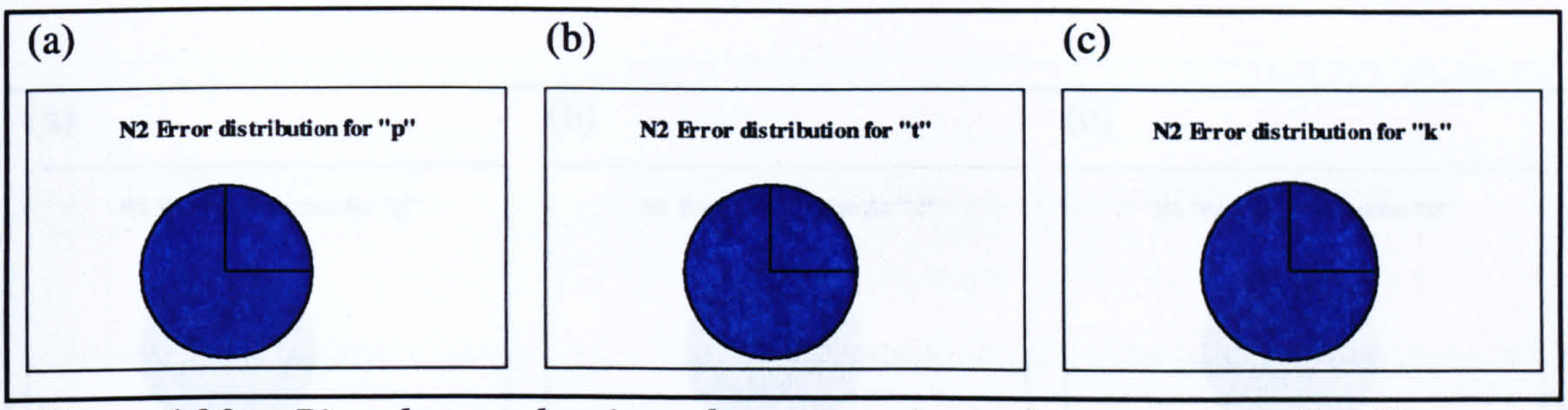

Figure 4.20 Pie charts showing the proportion of correct, predictable and non-predictable productions in N2's monosyllabic repetitions (a) /pə/ (b) /tə/ and (c) /kə/.

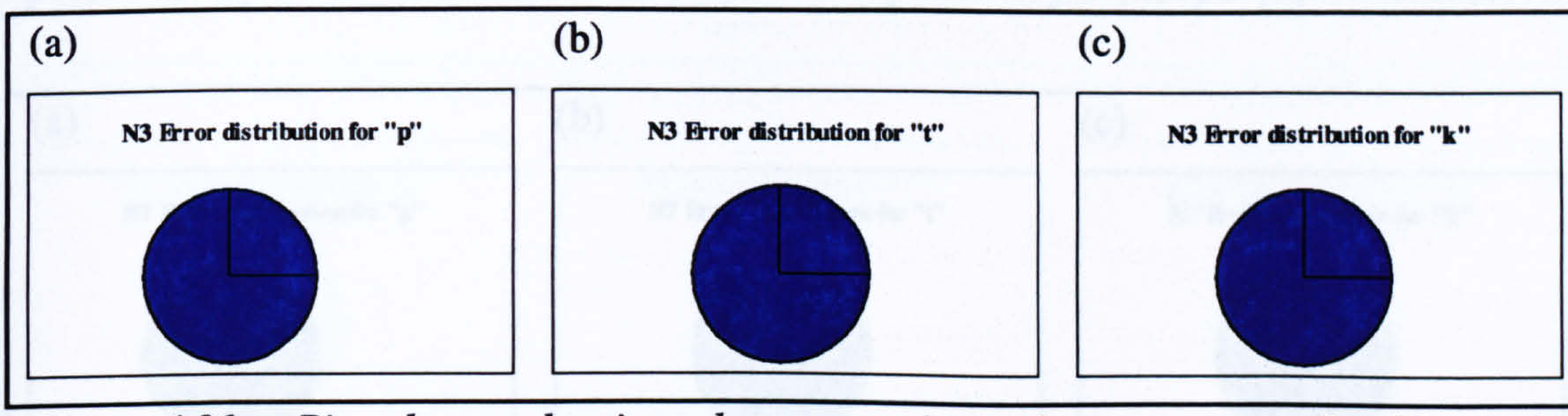

Figure 4.21 Pie charts showing the proportion of correct, predictable and non-predictable productions in N3's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

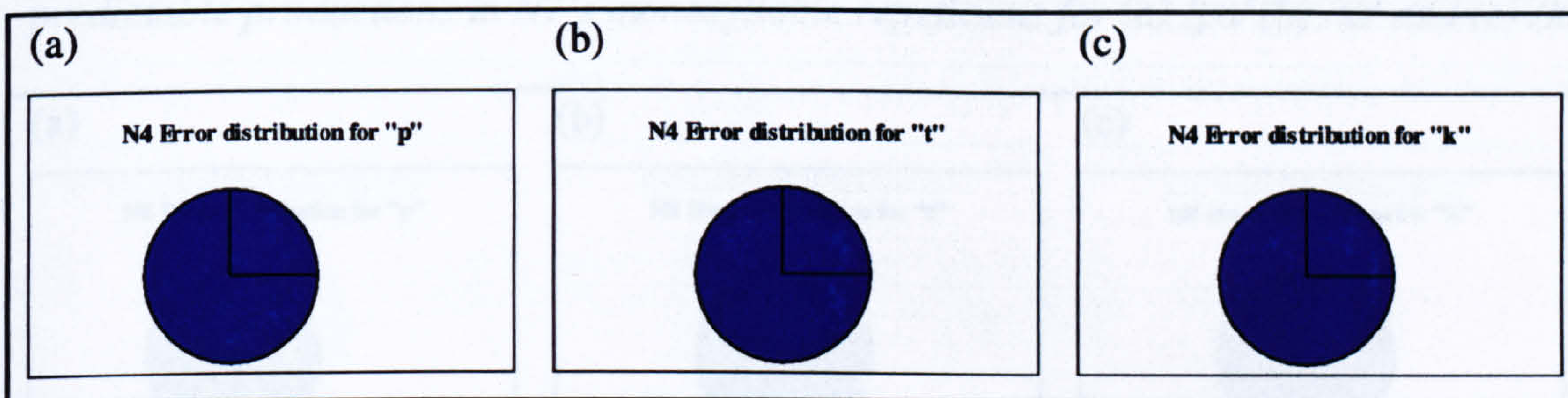

Figure 4.22 Pie charts showing the proportion of correct, predictable and non-predictable productions in N4's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

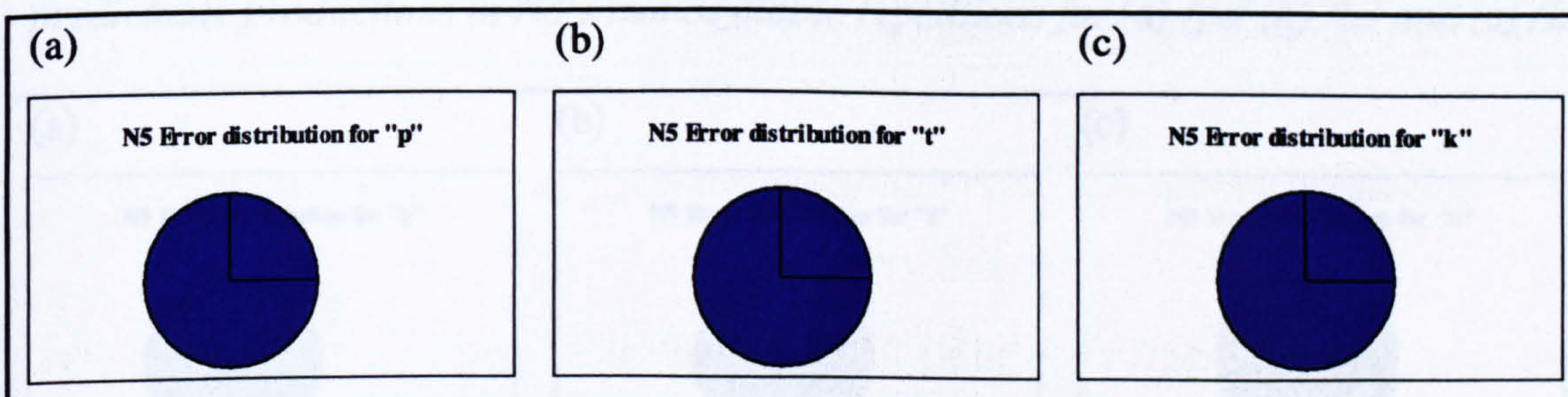

Figure 4.23 Pie charts showing the proportion of correct, predictable and non-predictable productions in N5's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

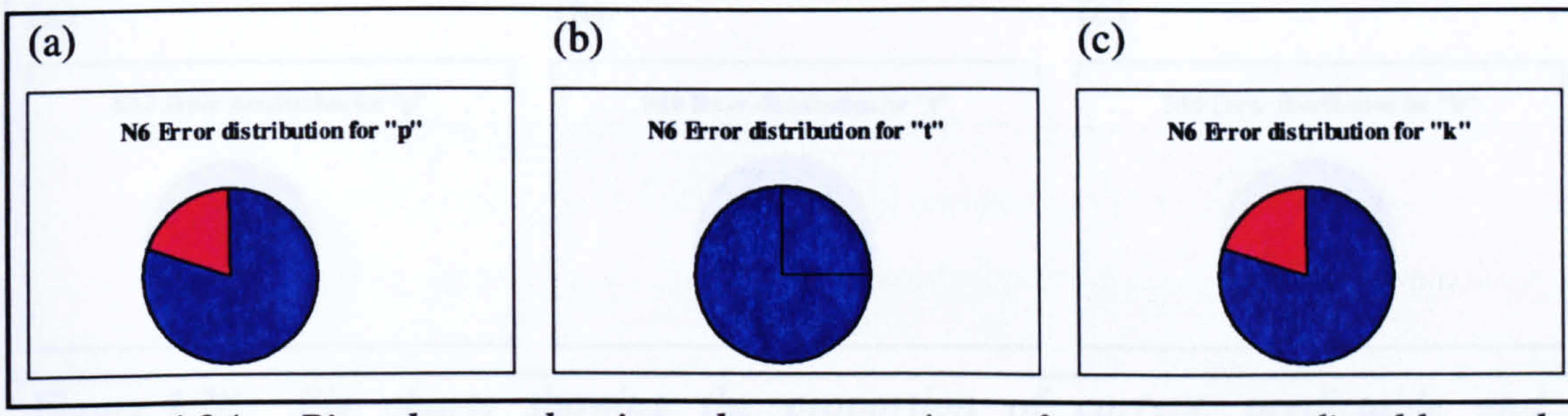

Figure 4.24 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N6's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

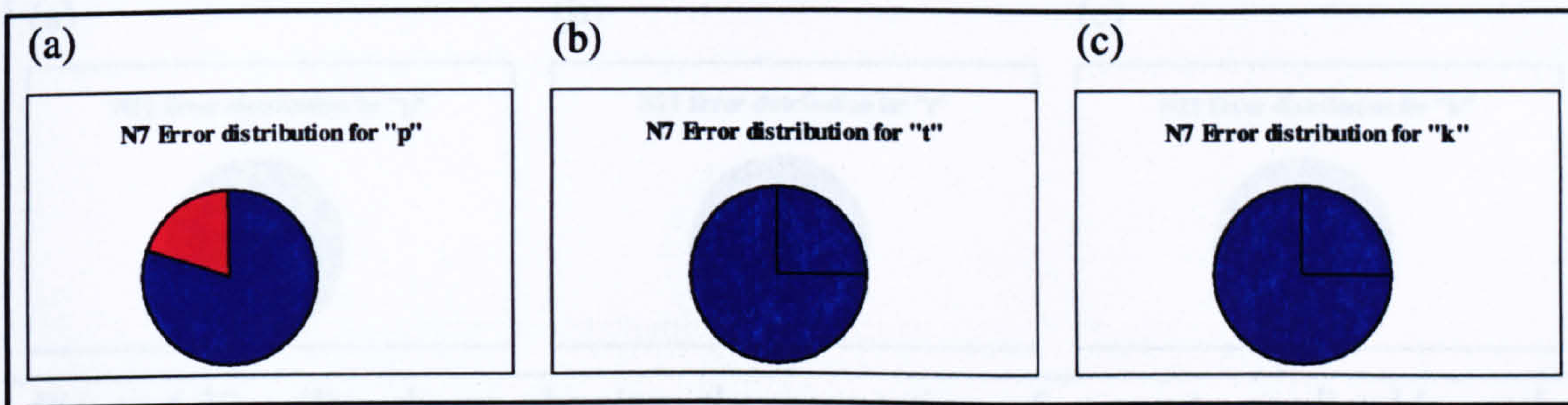

Figure 4.25 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N7's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

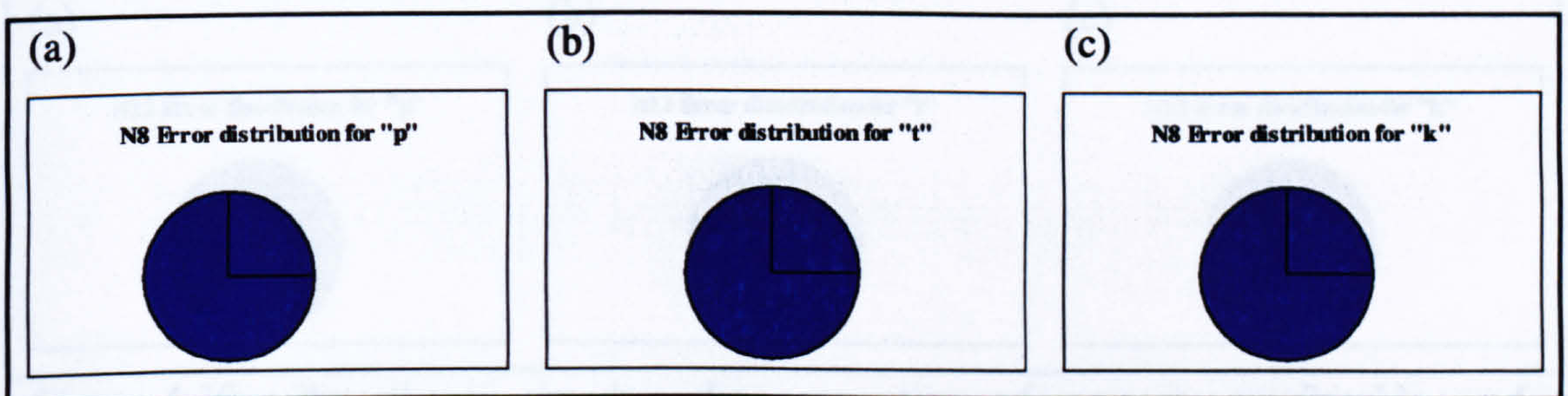

Figure 4.26 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N8's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

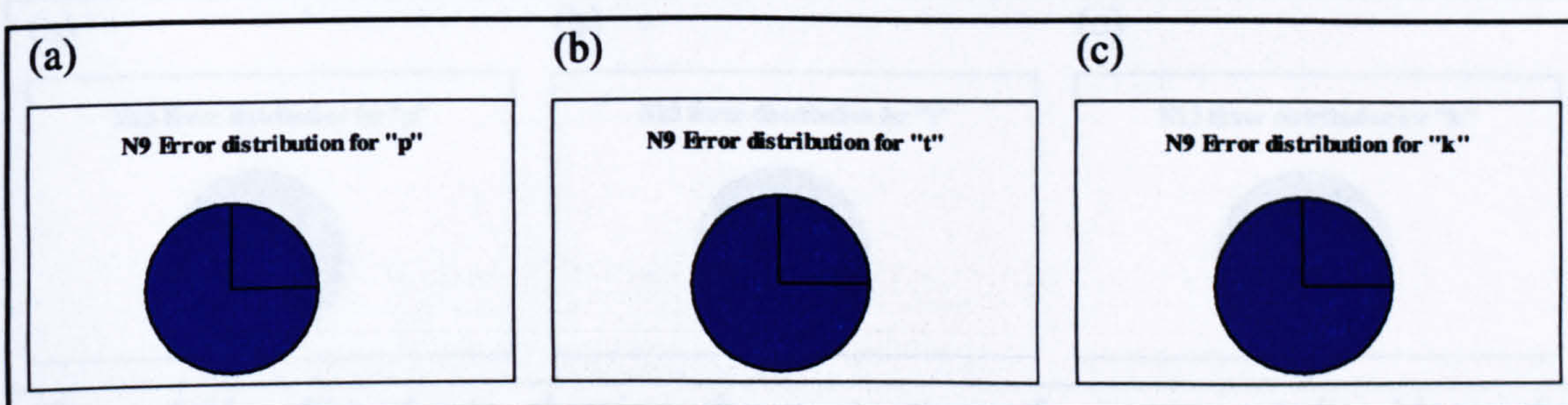

Figure 4.27 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N9's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

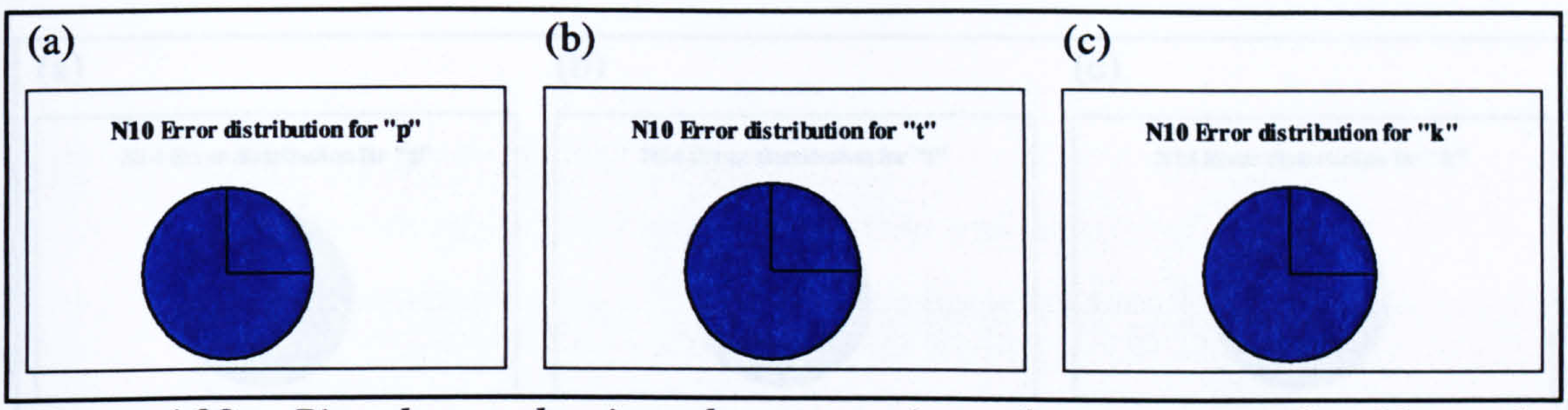

Figure 4.28 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N10's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

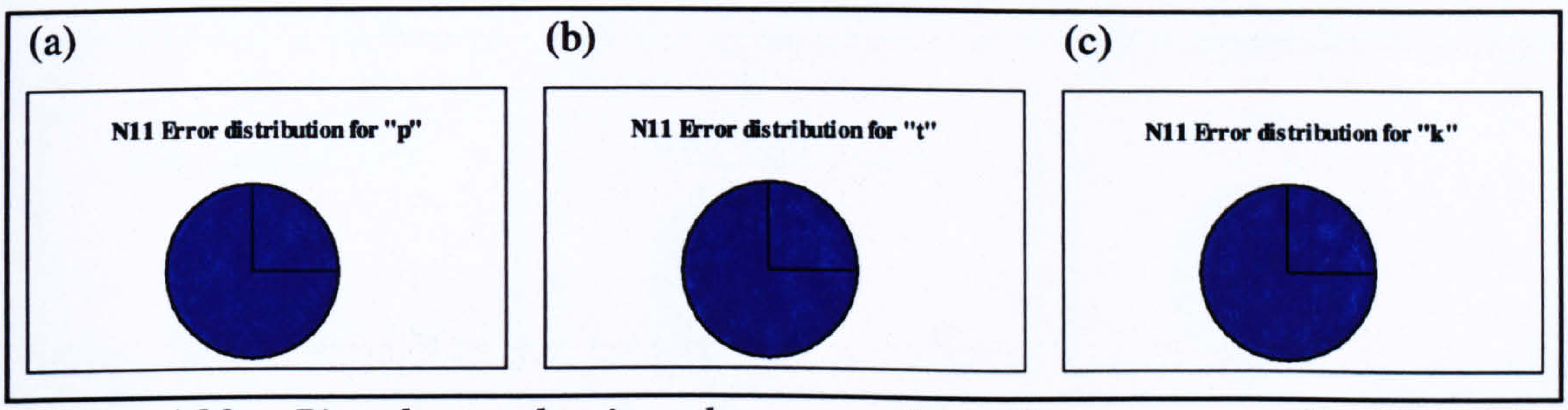

Figure 4.29 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N11's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

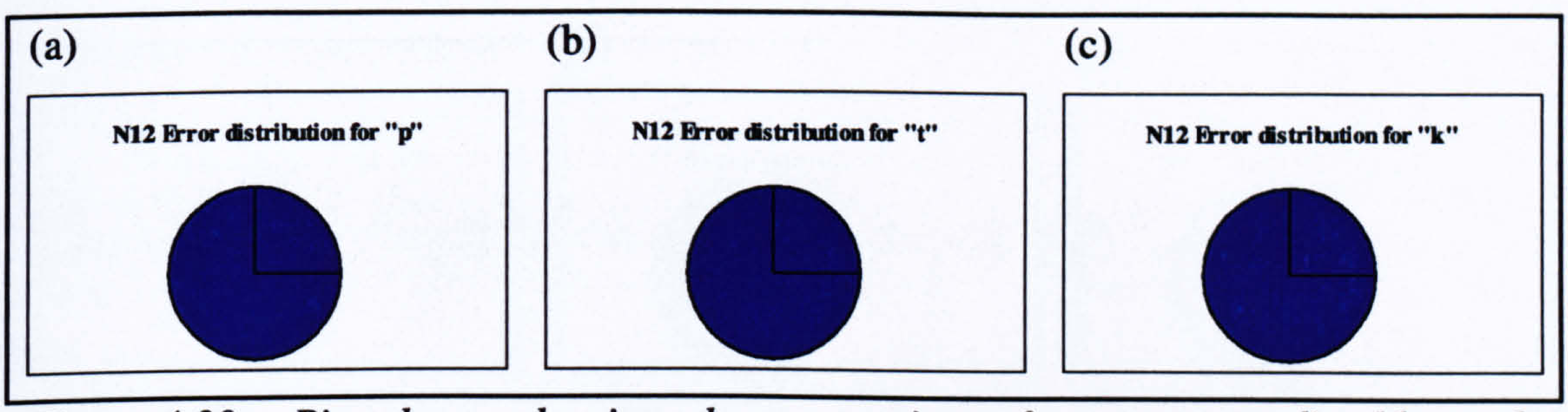

Figure 4.30 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N12's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

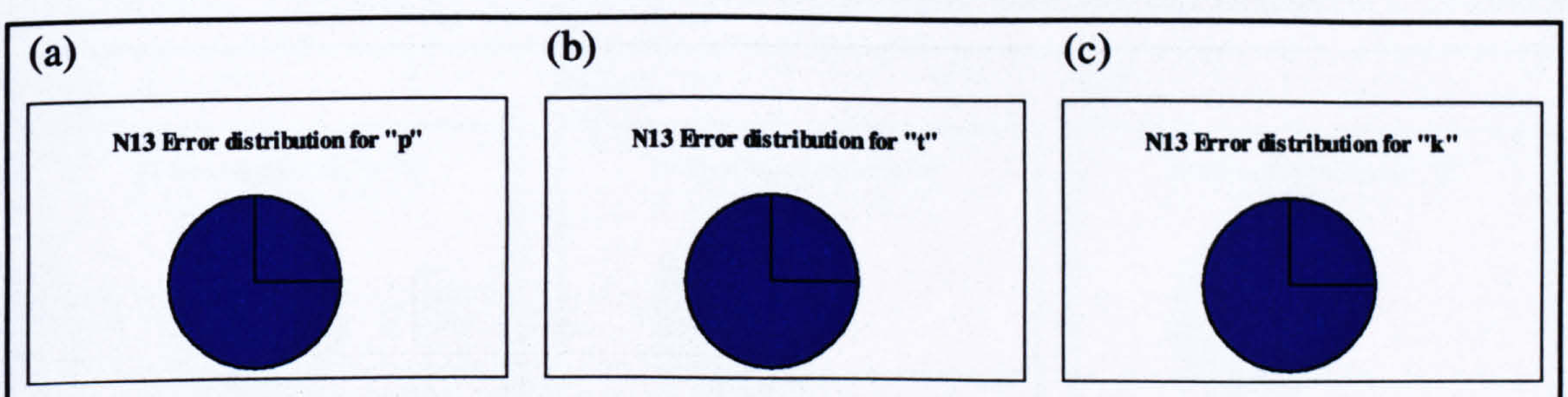

Figure 4.31 *Pie charts showing the proportion of correct, predictable and non-predictable productions in N13's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.*

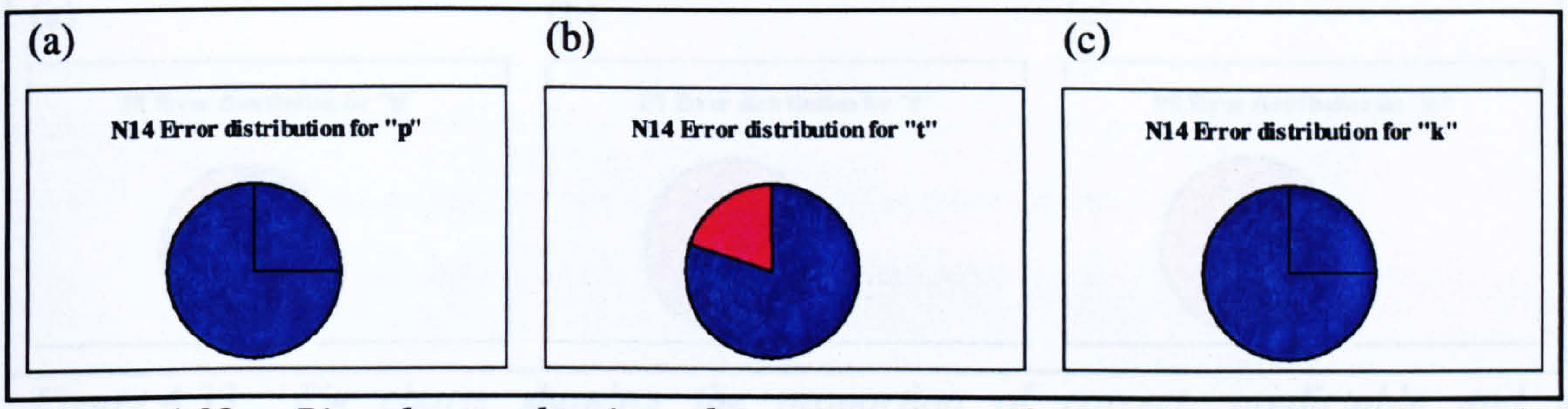

Figure 4.32 Pie charts showing the proportion of correct, predictable and non-predictable productions in N14's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

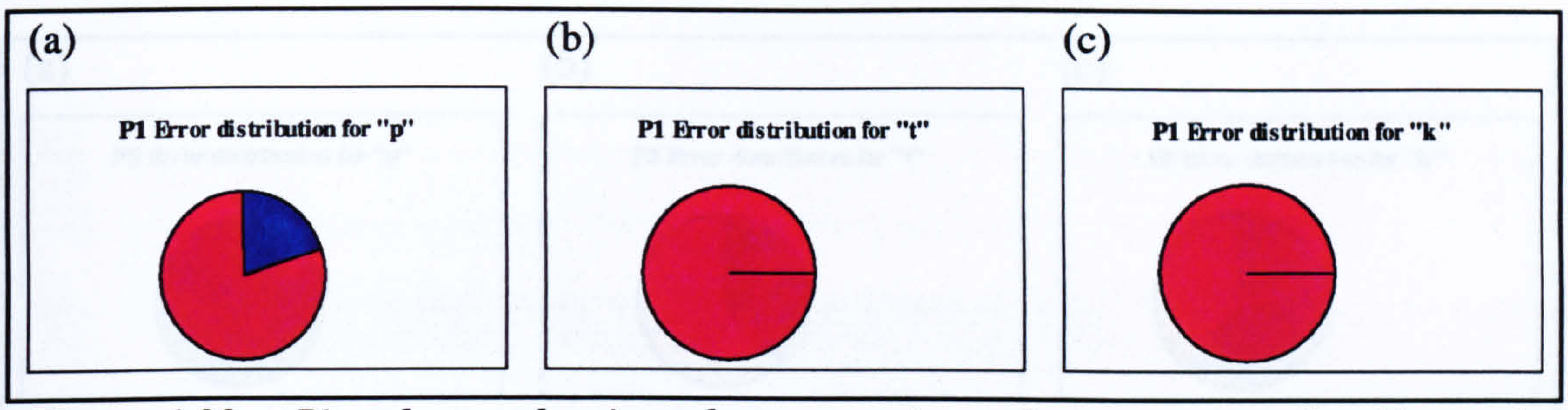

Figure 4.33 Pie charts showing the proportion of correct, predictable and non-predictable productions in P1's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

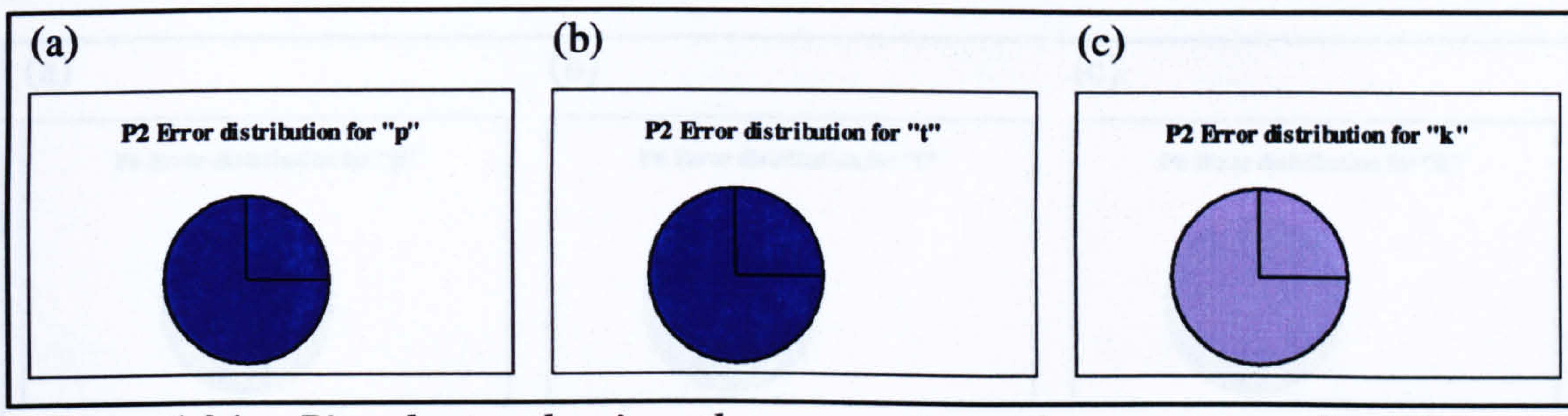

Figure 4.34 Pie charts showing the proportion of correct, predictable and non-predictable productions in P2's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

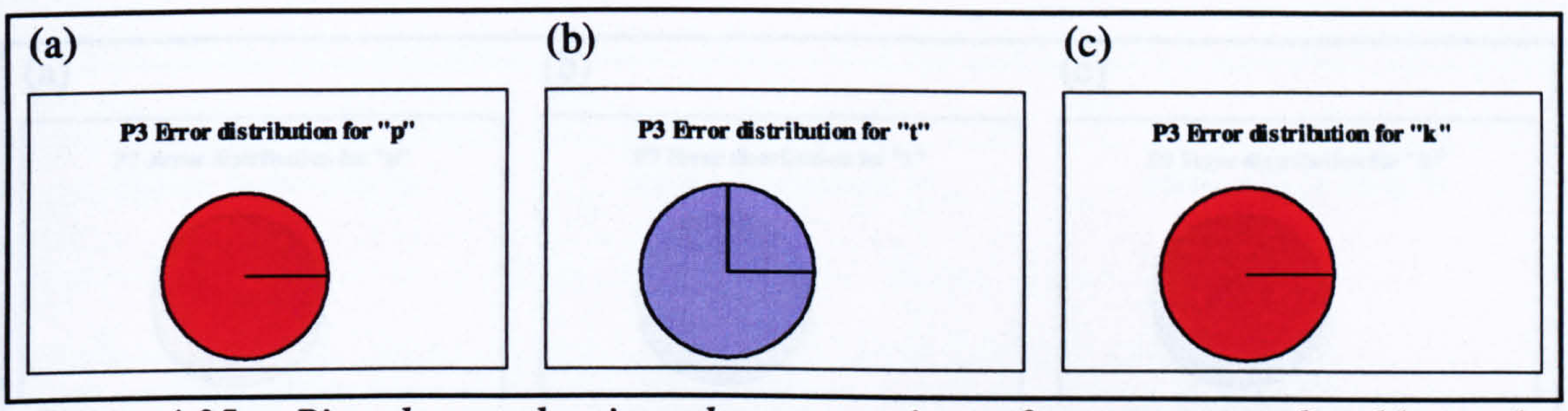

Figure 4.35 Pie charts showing the proportion of correct, predictable and non-predictable productions in P3's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

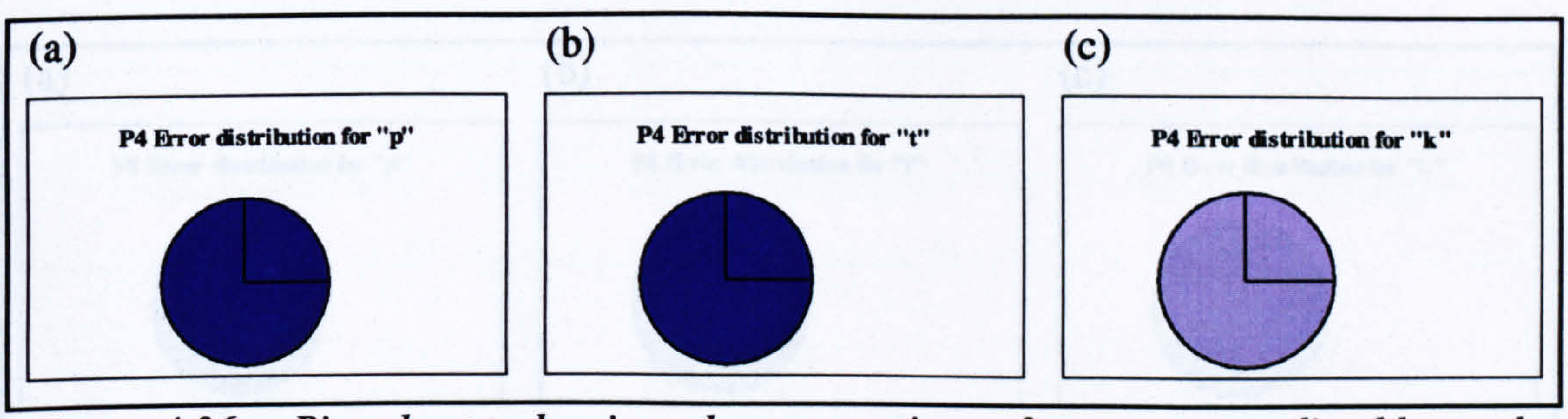

Figure 4.36 Pie charts showing the proportion of correct, predictable and non-predictable productions in P4's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

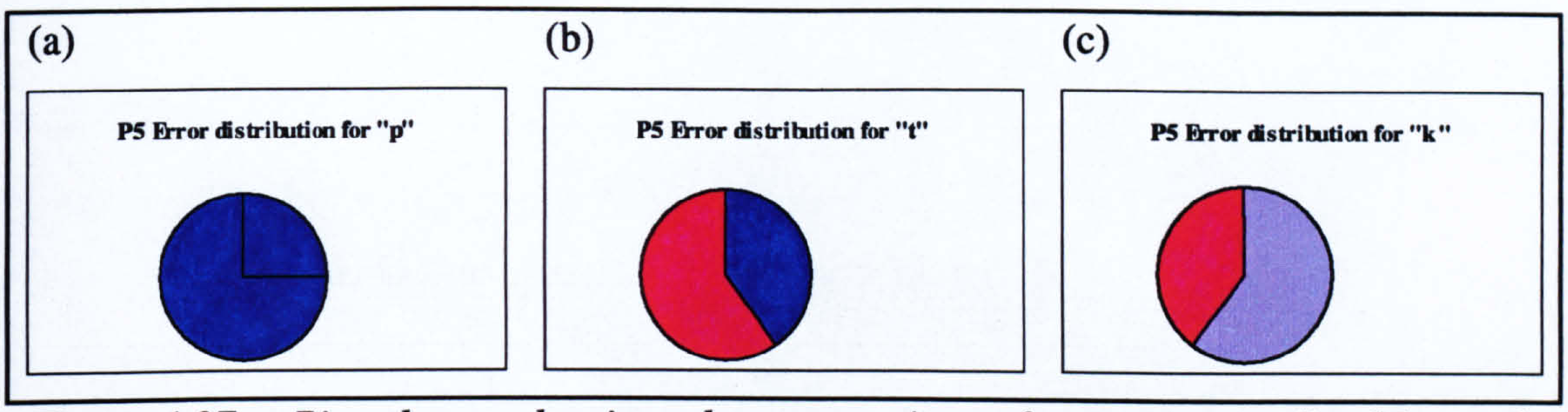

Figure 4.37 Pie charts showing the proportion of correct, predictable and non-predictable productions in P5's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

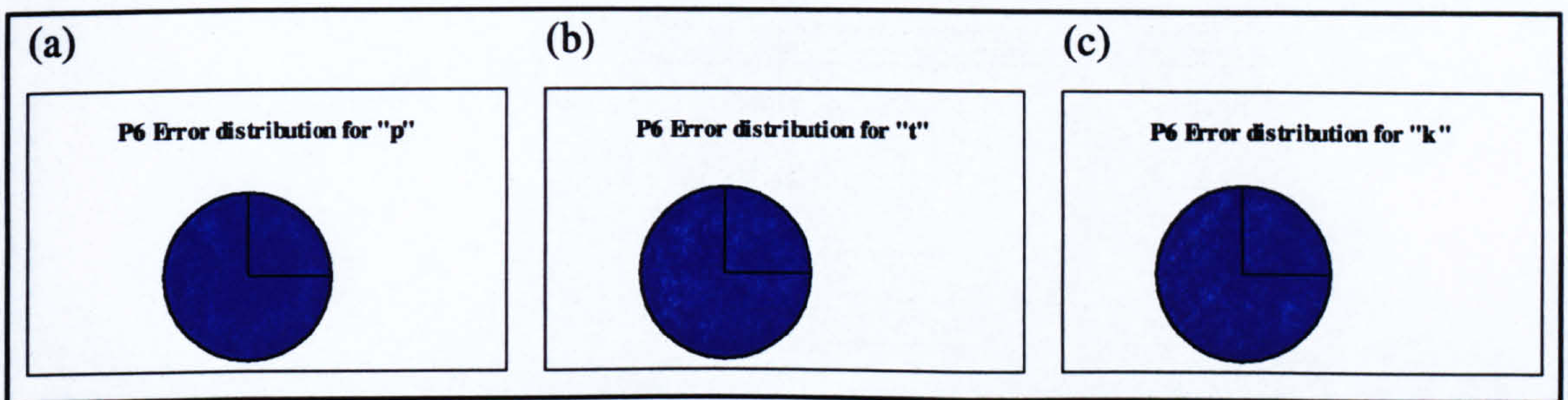

Figure 4.38 Pie charts showing the proportion of correct, predictable and non-predictable productions in P6's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

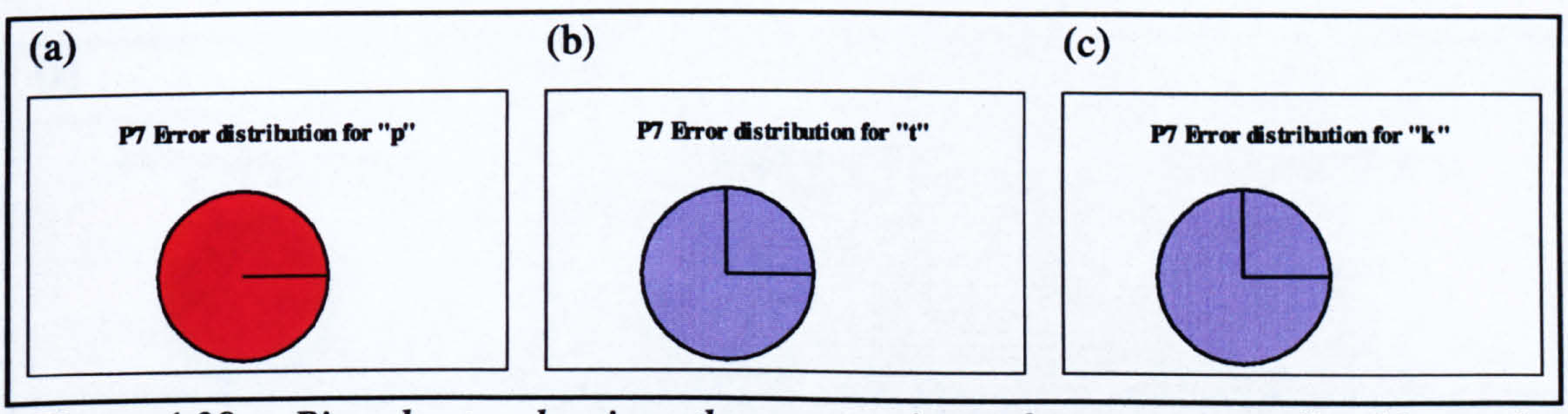

Figure 4.39 Pie charts showing the proportion of correct, predictable and non-predictable productions in P7's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

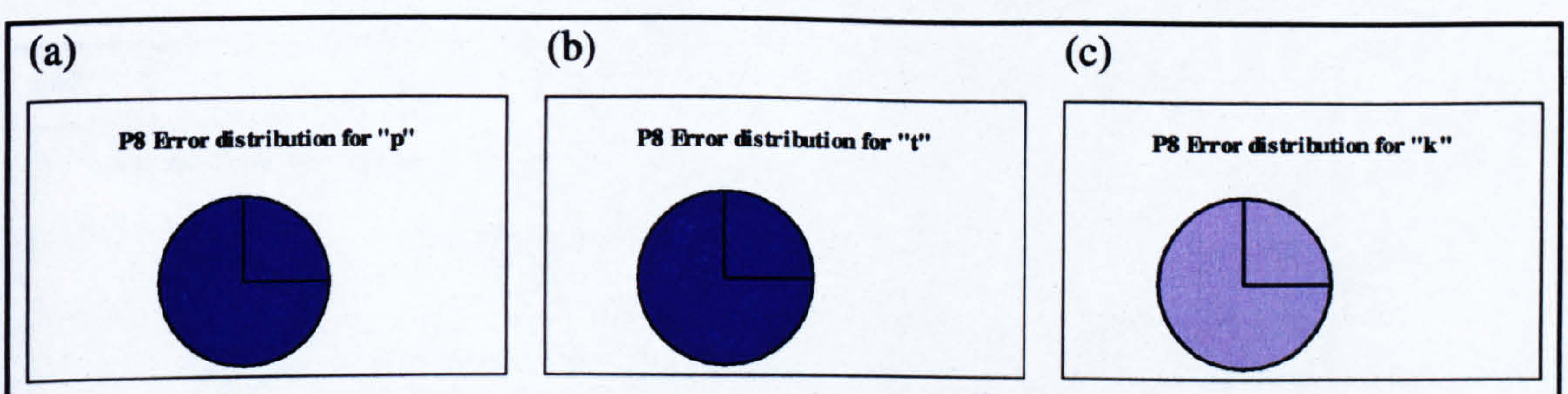

Figure 4.40 Pie charts showing the proportion of correct, predictable and non-predictable productions in P8's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

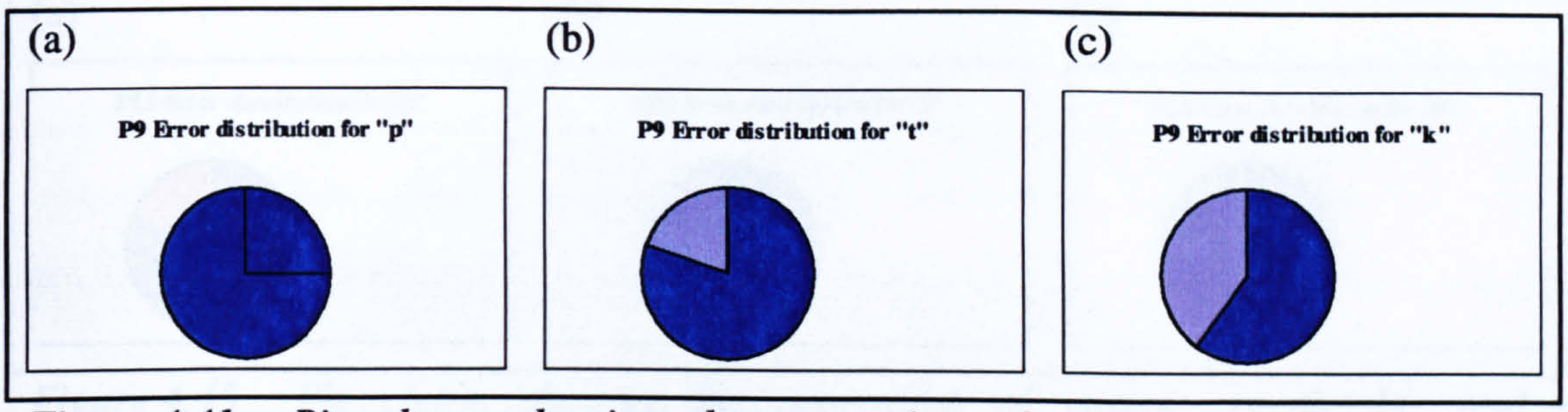

Figure 4.41 Pie charts showing the proportion of correct, predictable and non-predictable productions in P9's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

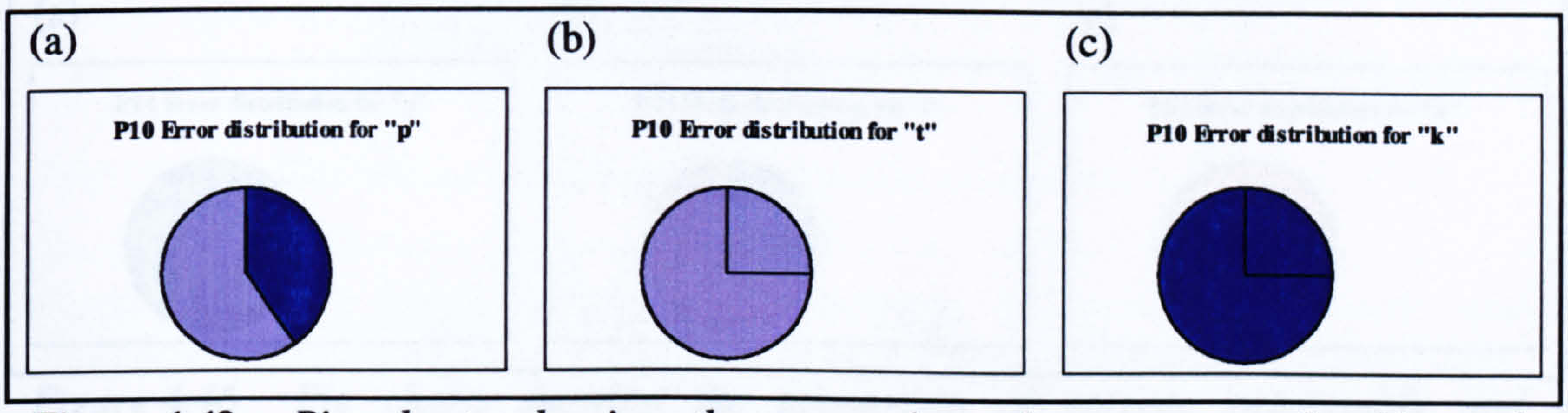

Figure 4.42 Pie charts showing the proportion of correct, predictable and non-predictable productions in P10's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

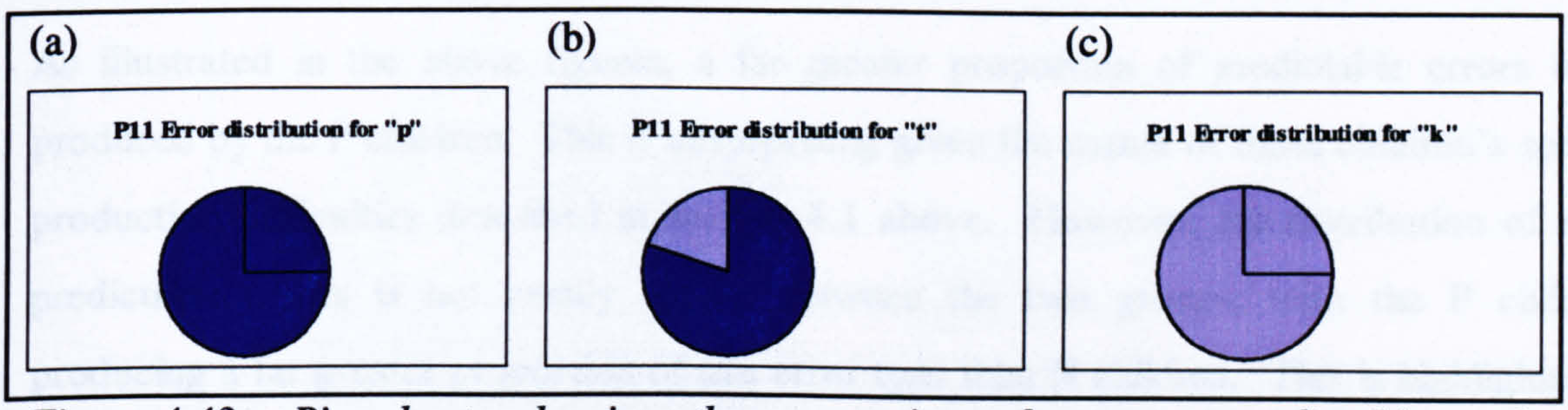

Figure 4.43 Pie charts showing the proportion of correct, predictable and non-predictable productions in P11's monosyllabic repetitions (a) /pə/ (b) /tə/ and (c) /kə/.

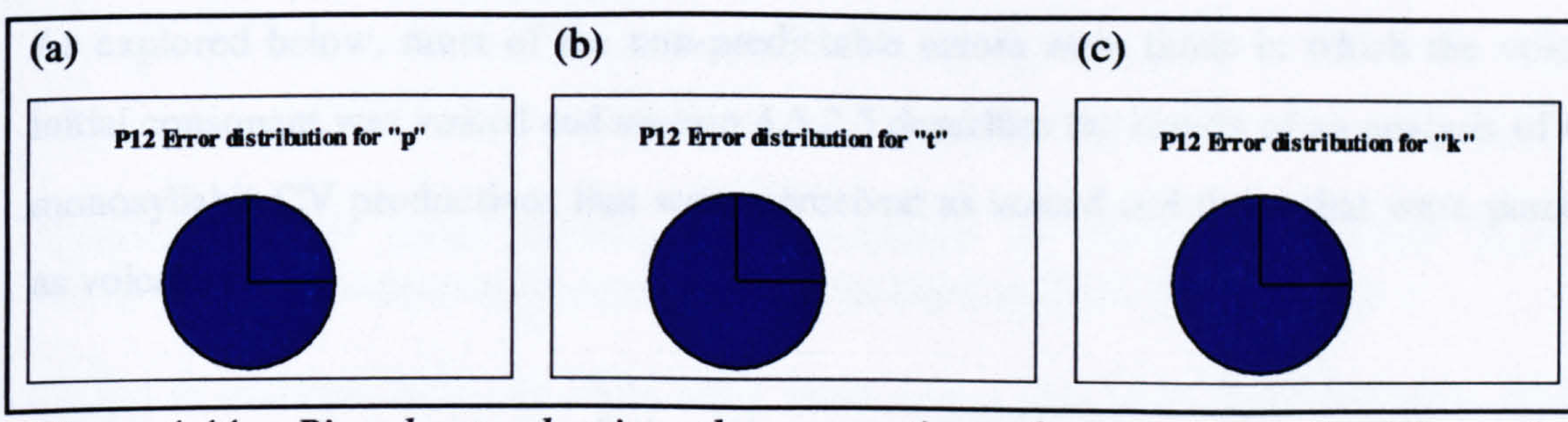

Figure 4.44 Pie charts showing the proportion of correct, predictable and non-predictable productions in P12's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

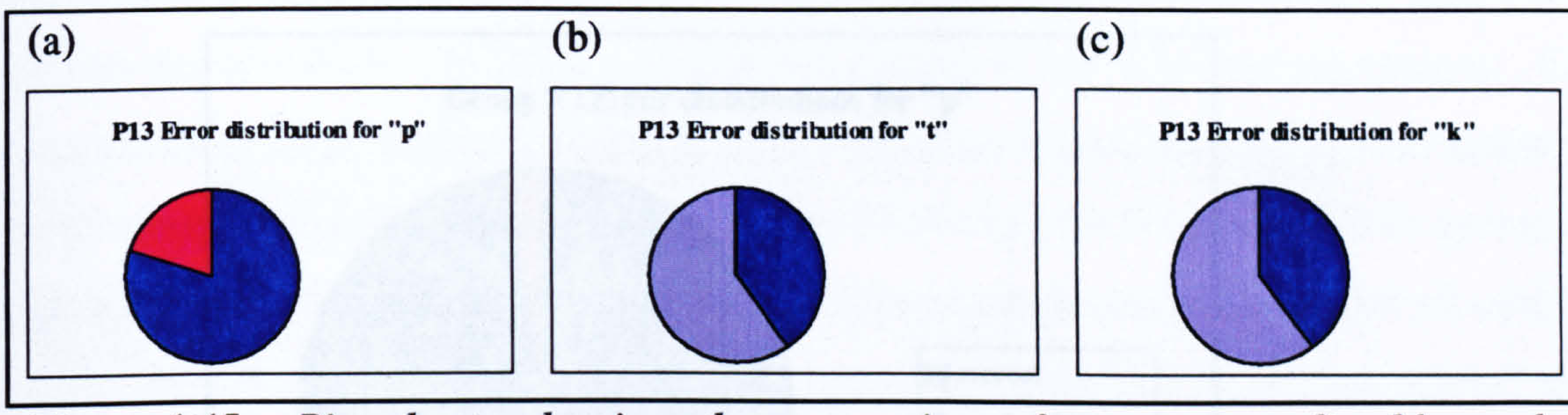

Figure 4.45 Pie charts showing the proportion of correct, predictable and non-predictable productions in P13's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

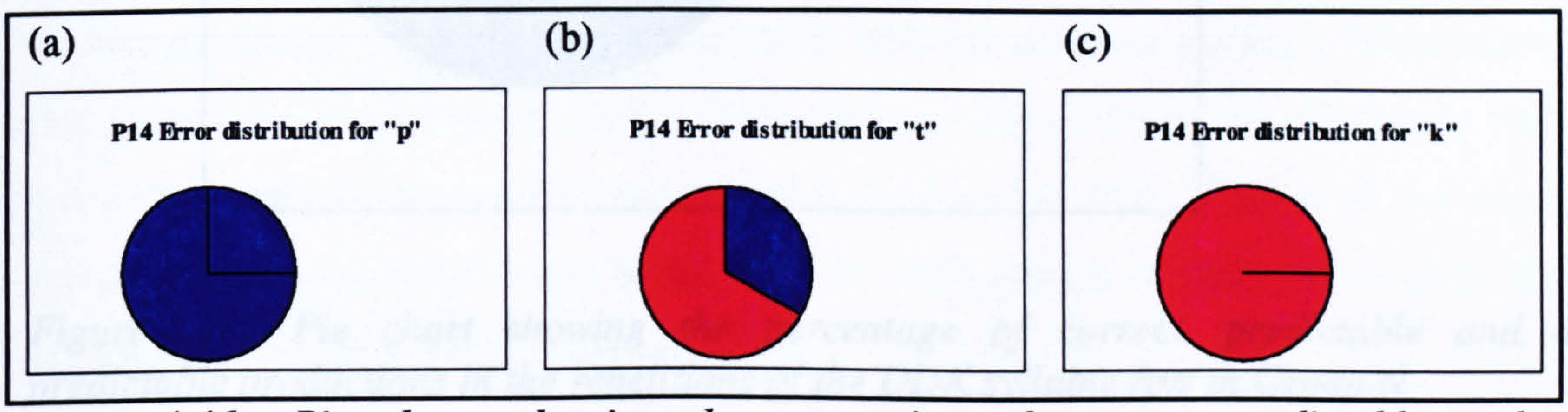

Figure 4.46 Pie charts showing the proportion of correct, predictable and non-predictable productions in P14's monosyllabic repetitions for (a) /pə/ (b) /tə/ and (c) /kə/.

As illustrated in the above figures, a far greater proportion of predictable errors were produced by the P children. This is unsurprising given the nature of these children's speech production difficulties described in section 4.1 above. However, the distribution of non-predictable errors is not evenly spread between the two groups, with the P children producing a far greater proportion of this error type than N children. This is highlighted in the following sections where the above data was drawn together to give group totals for correct, predictable and non-predictable productions.

As explored below, most of the non-predictable errors were those in which the voiceless initial consonant was voiced and section 4.5.2.5 describes the results of an analysis of those monosyllabic CV productions that were perceived as voiced and those that were perceived as voiceless.

4.5.2.1 *Group error analysis of the monosyllabic sequence /pə/*

Figures 4.47 and 4.48 show the distribution of errors for the productions of the syllable /pə/ for each group as a whole.

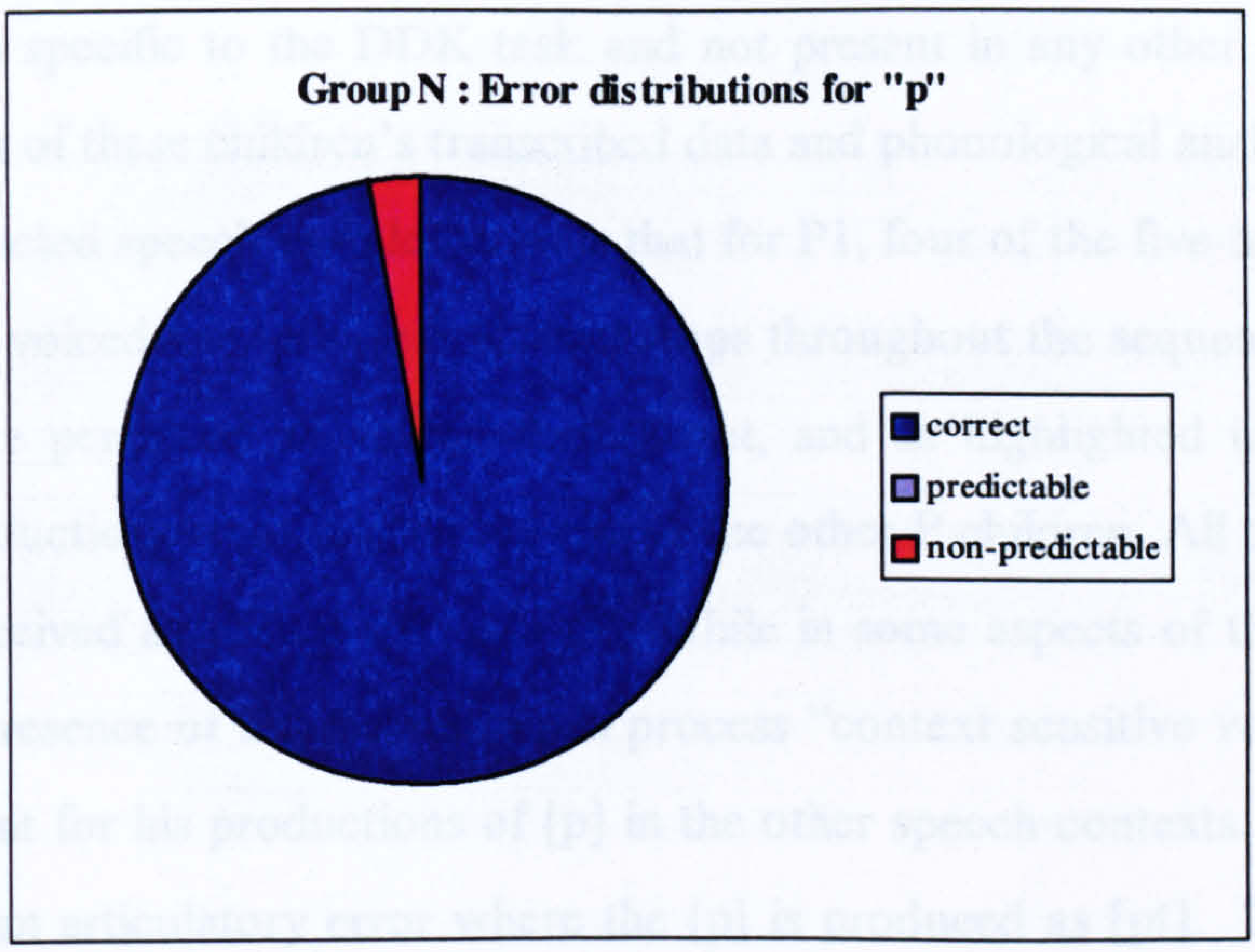

Figure 4.47 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /pə/ in Group N

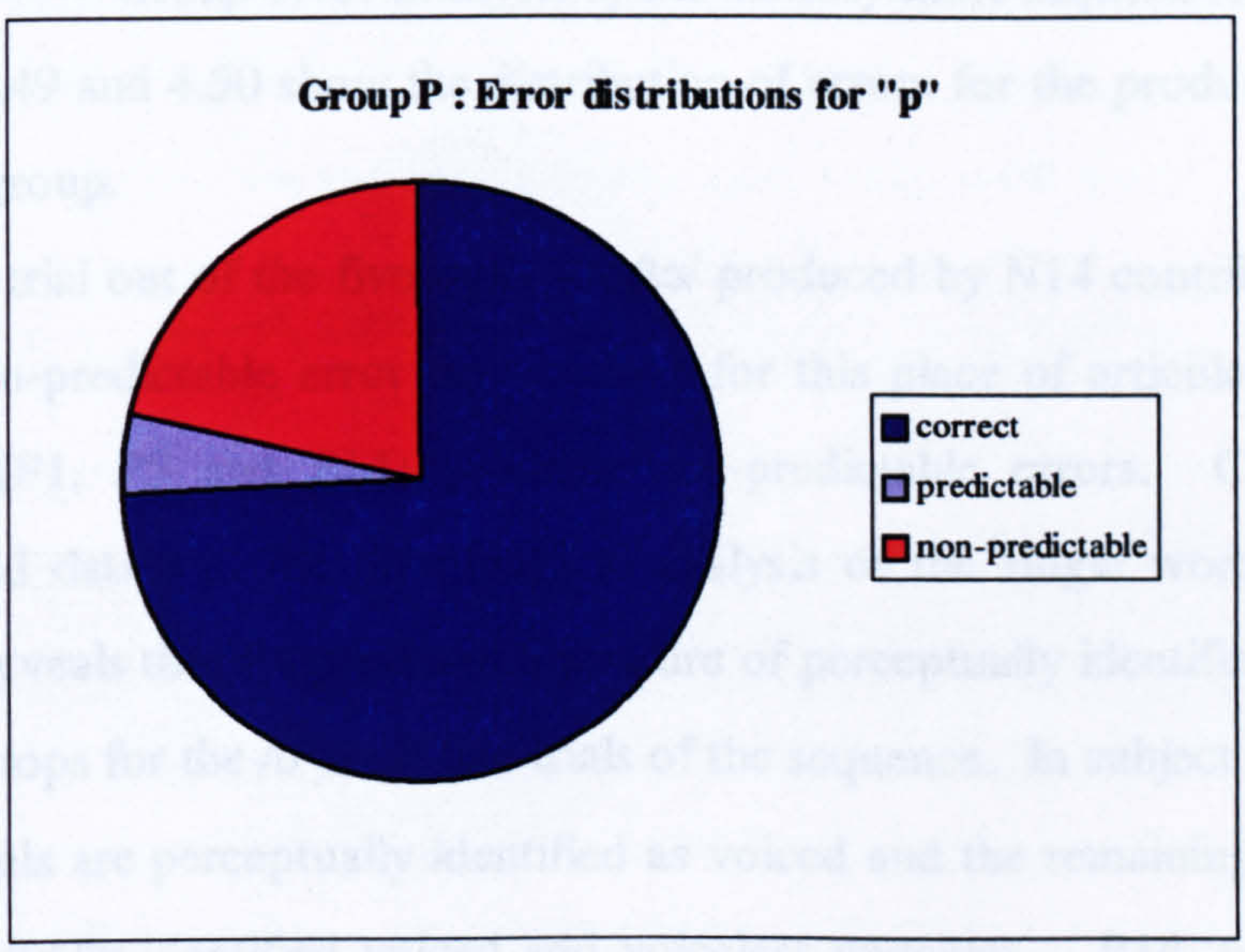

Figure 4.48 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /pə/ in Group P

Of the N children, only one child (N6) made errors that were not-predictable from his spontaneous speech patterns. Inspection of the transcribed data reveals that this error, where the /p/ of the CV was perceived as voiced, occurs in only one of the five DDK trials. This substitution is not however consistent over the whole sequence, where the majority of the syllables are perceptually identified as the voiceless cognate.

Four of the P children (P1, P3, P7 and P13) produce non-predictable errors. These precise errors are specific to the DDK task and not present in any other speech context. Closer inspection of these children's transcribed data and phonological analysis of their single word and connected speech samples reveals that for P1, four of the five trials contain perceptually identified voiced and voiceless bilabial stops throughout the sequence; for P3 all of the five trials were perceived as voiced throughout, and as highlighted in section 4.3.4.1 above, these productions were faster than any of the other P children. All the trials produced by P7 were perceived as voiced throughout. While in some aspects of this child's speech output there is presence of the simplification process "context sensitive voicing", this process was not present for his productions of [p] in the other speech contexts. For P13, only one trial contains an articulatory error where the [p] is produced as [pf]. Thus in all but one case, the non-predictable error found in the data for both groups of children, involves that of realising the voiceless bilabial stop as voiced.

4.5.2.2 *Group error analysis of the monosyllabic sequence /tə/*

Figures 4.49 and 4.50 show the distribution of errors for the productions of the syllable /tə/ for each group.

Only one trial out of the five trials for /tə/ produced by N14 contributes to the group totals of the non-predictable error distributions for this place of articulation. In group P, three children (P1, P5 and P14) produce non-predictable errors. Closer inspection of the transcribed data and the phonological analysis of the single word and connected speech samples reveals that P1 produces a mixture of perceptually identifiable voiced and voiceless alveolar stops for the /t/ in all five trials of the sequence. In subject P5, all the alveolar stops in two trials are perceptually identified as voiced and the remaining trials contain a mixture of perceptually identified voiced and voiceless cognates. P14, who only produced three trials in total, produced one accurately, and in the other two substituted the /t/ with a [p]. This pattern was not found in this subject's single or connected speech data.

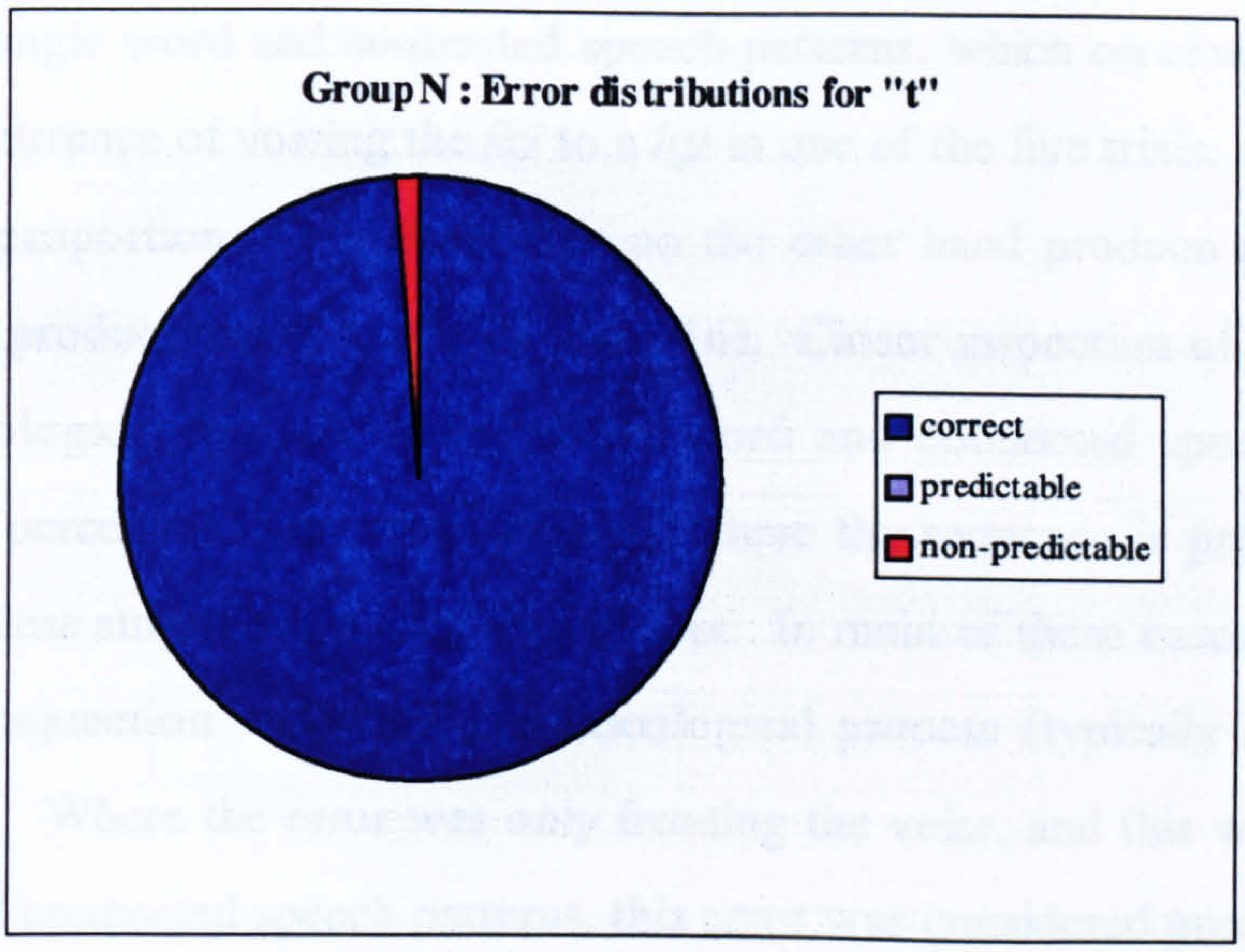

Figure 4.49 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /tə/ in Group N

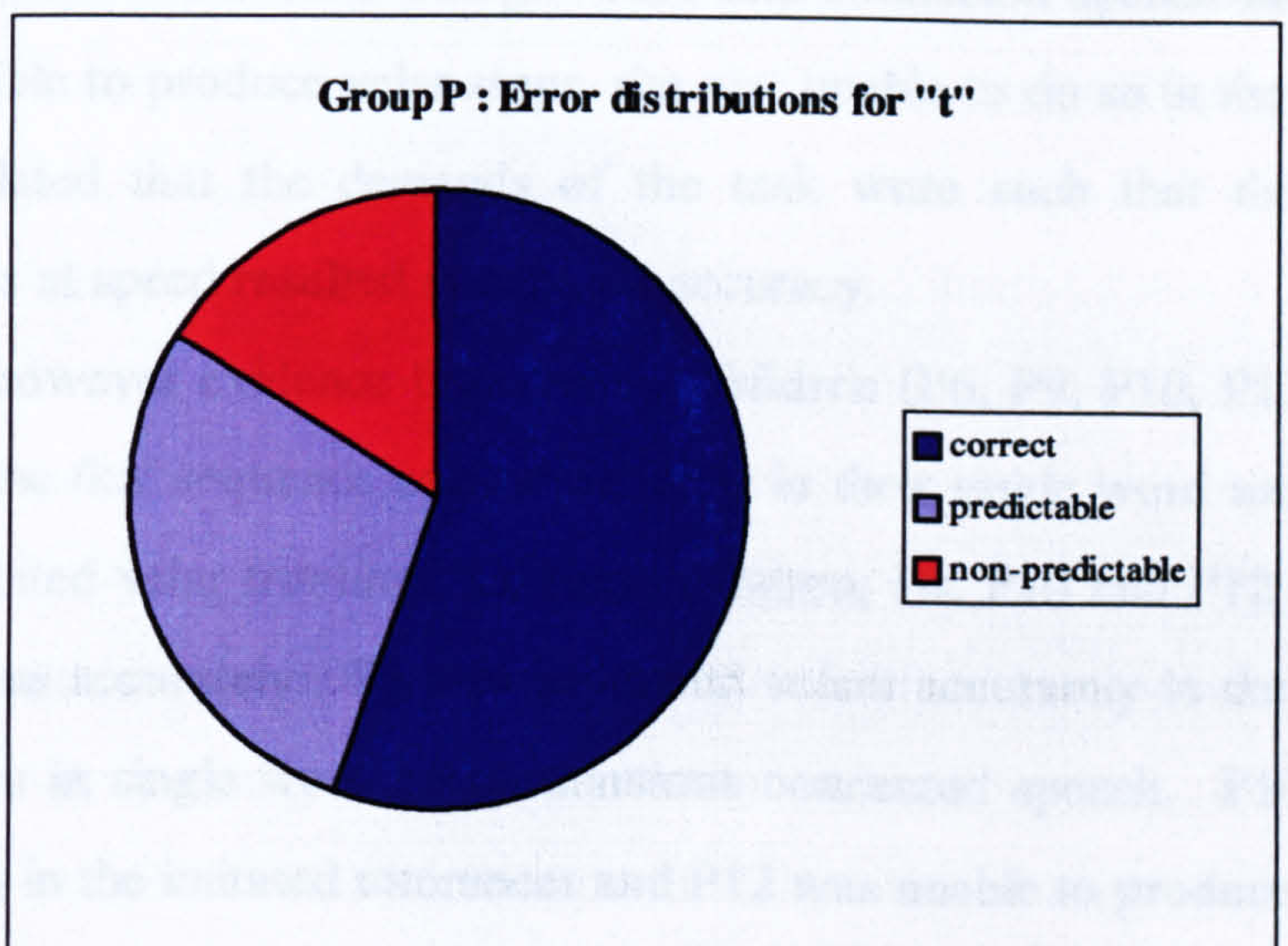

Figure 4.50 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /tə/ in Group P

4.5.2.3 *Group error analysis of the monosyllabic sequence /kə/*

Figures 4.51 and 4.52 show the distribution of errors for the productions of the syllable /kə/ for each group.

For the velar stop, only one of the N children (N6) made an error non-predictable on the basis of single word and connected speech patterns, which on closer inspection of the data is the occurrence of voicing the /k/ to a /g/ in one of the five trials.

A larger proportion of the P children on the other hand produce non-predictable errors in their /kə/ productions (P1, P3, P5 and P14). Closer inspection of the transcribed data and the phonological analysis of the single word and connected speech samples reveals that these are perceived as errors of voicing, where the sequence is produced with both voiced and voiceless stops or is voiced throughout. In most of these cases, the addition of voicing was in conjunction with another phonological process (typically fronting the velar to an alveolar). Where the error was only fronting the velar, and this was typical of that child's single and connected speech patterns, this error was considered predictable.

Child P14 however produced all her trials for /kə/ as /pə/, suggesting that this child in particular had greater difficulty in mastering the task as she consistently produced /pə/ regardless of the required production for each place of articulation. Inspection of the transcriptions of this child's single word and connected speech samples reveals that while she was able to produce velar stops, she was unable to do so in the DDK task, where it can be speculated that the demands of the task were such that the effort to produce the repetitions at speed resulted in reduced accuracy.

There is however evidence that some P children (P6, P9, P10, P12 and P13) were able to produce the /kə/ sequence accurately while in their single word and connected speech data they exhibited velar fronting. Of these children, P6, P10 and P12 produced all their DDK productions accurately. P6 also produced velars accurately in the imitated utterances but not always in single word or spontaneous connected speech. P10 produced some velars accurately in the imitated utterances and P12 was unable to produce an accurate velar in the imitated utterances. P9 and P13 on the other hand produced some velar targets accurately in the DDK sequence while in the other trials fronted the velar to an alveolar stop. This would suggest that these children demonstrate emerging stimulabilty for velar production when presented with an accurate model target.

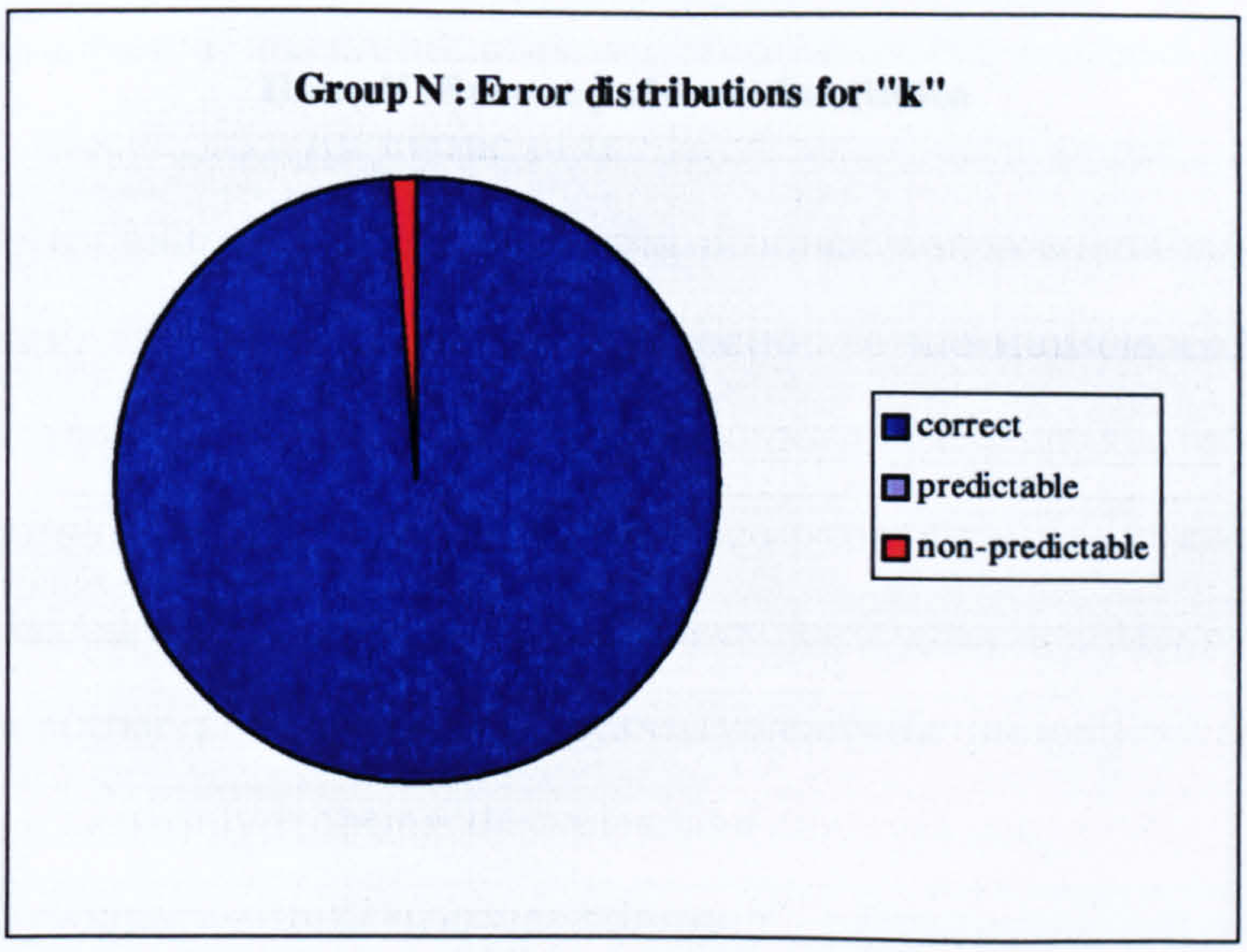

Figure 4.51 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /kə/ in Group N

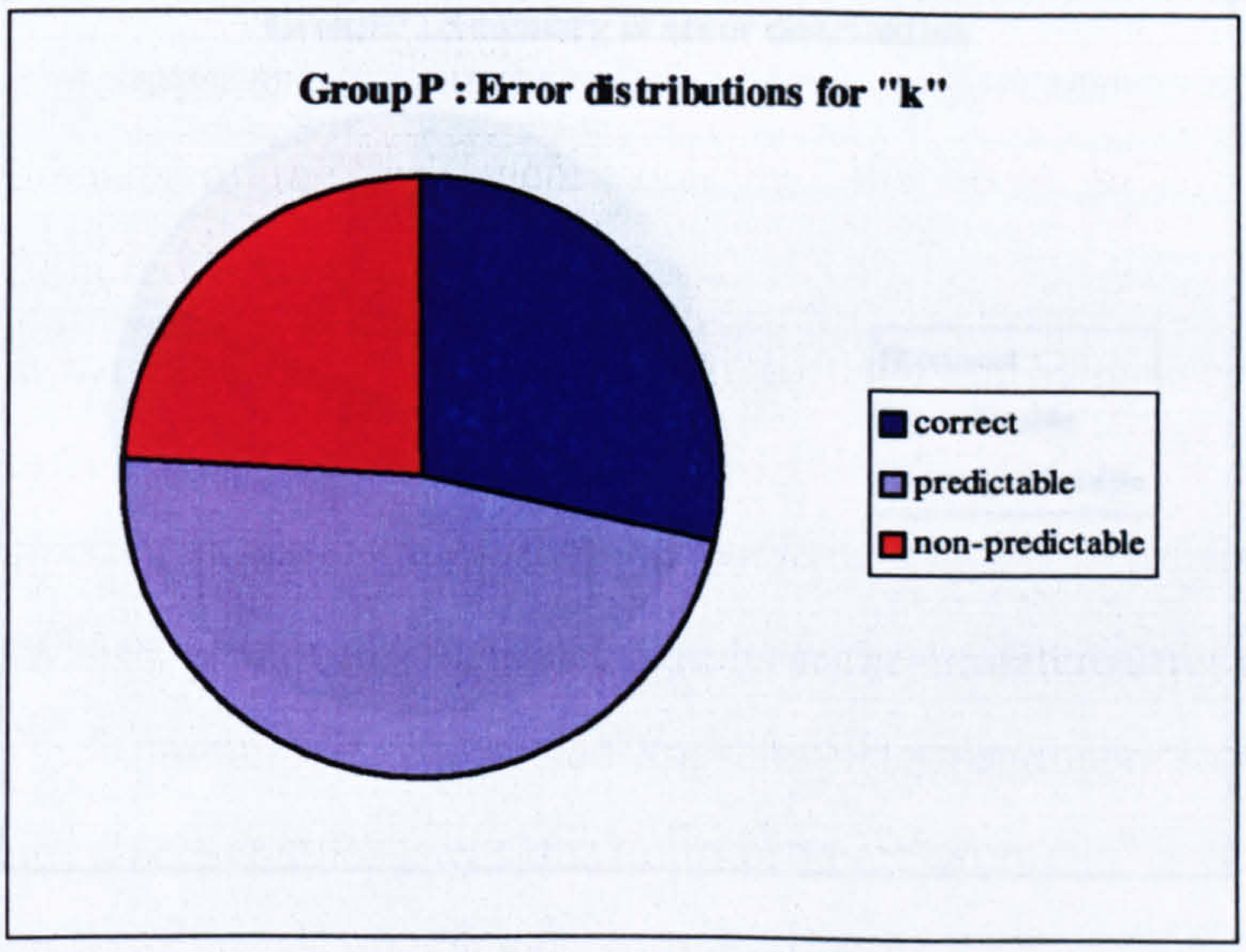

Figure 4.52 Pie chart showing the percentage of correct, predictable and non-predictable productions in the repetitions of the DDK syllable /kə/ in Group P

4.5.2.4 *Summary of the error analysis of the monosyllabic sequences combined*

Figures 4.53 and 4.54 show the distribution of errors for the productions of all the monosyllabic sequence combined.

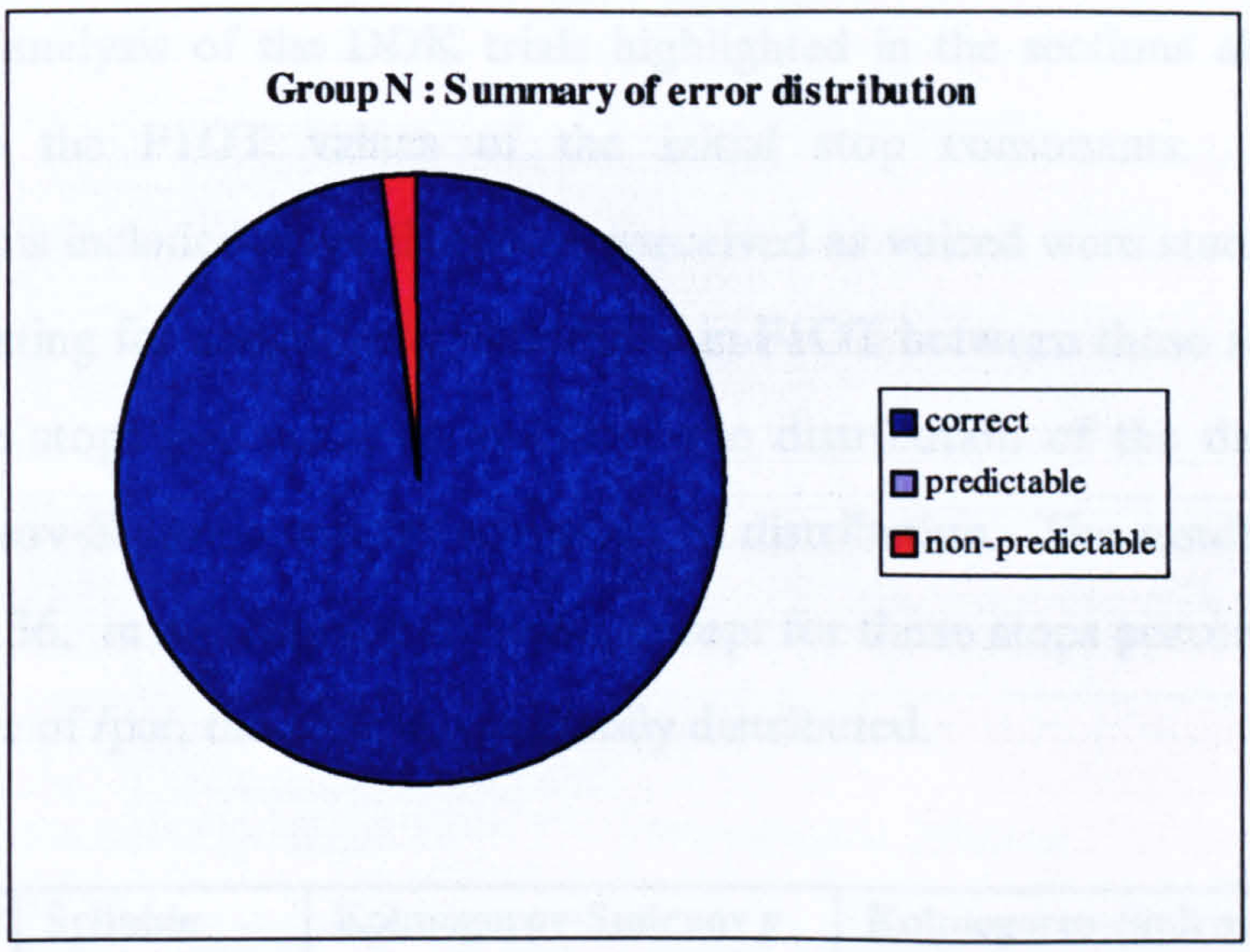

Figure 4.53 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the monosyllabic DDK repetitions for Group N

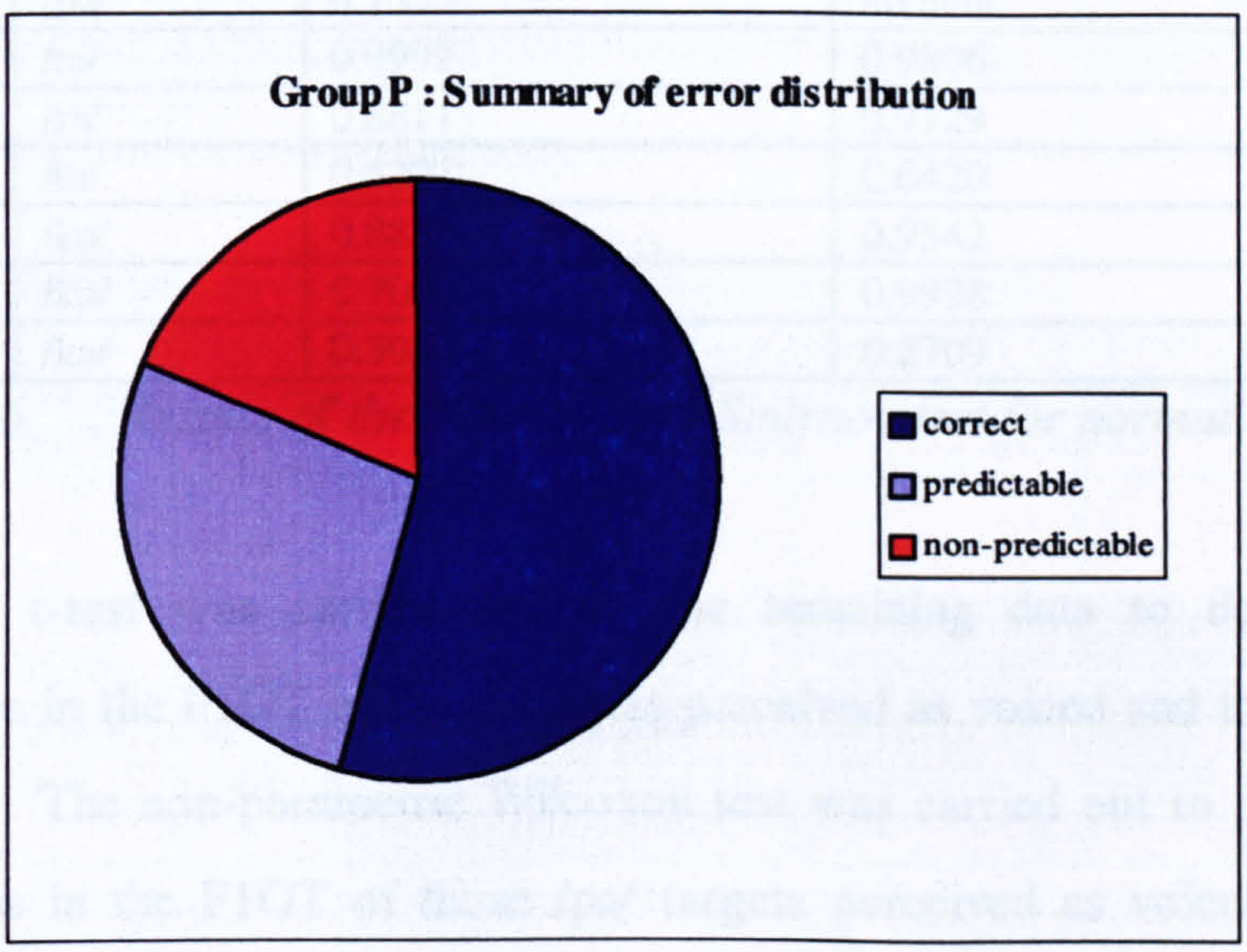

Figure 4.54 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the monosyllabic DDK repetitions for Group P

To summarise, it is evident that the P children produce a greater number of non-predictable errors that are not typical of the children's single word and connected speech patterns.

In the majority of cases, this error has been one where the stop consonant has been realised as voiced. For this reason, further analysis of the data in the following section inspects the F1 onset times (F1OT) (see chapter three section, 3.5.6.5) of the DDK productions of those children who made such errors, to investigate the F1OT of those productions that were perceived as voiced and those that were perceived as voiceless.

4.5.2.5 *F1OT analysis of the monosyllabic productions perceived as voiced*

Acoustic analysis of the DDK trials highlighted in the sections above was carried out to determine the F1OT values of the initial stop consonants. Those children whose productions included some that were perceived as voiced were studied.

Before testing for a significant difference in F1OT between those stops perceived as voiced and those stops perceived as voiceless the distribution of the data was tested using the Kolmogorov-Smirnov test for normality of distribution. The results of this analysis, shown in table 4.36, reveal that for all cases, except for those stops perceived as voiceless for N6's repetitions of /pə/, the data was normally distributed.

Subject	Syllable	Kolmogorov-Smirnov *p* value for stops perceived as voiced	Kolmogorov-Smirnov *p* value for stops perceived as voiceless
N6	/pə/	0.9992	0.0000
P1	/pə/	0.9989	0.7613
P3	/pə/	0.1812	no data
P7	/pə/	0.1365	no data
N14	/tə/	0.9992	0.9806
P1	/tə/	0.8811	0.9129
P5	/tə/	0.5207	0.6420
N6	/kə/	0.8825	0.9542
P1	/kə/	0.7000	0.9938
P5	/kə/	0.3010	0.2709

Table 4.36 Results of the Kolmogorov-Smirnov test for normality of distribution

A paired t-test was carried out on the remaining data to determine any significant differences in the F1OT of those targets perceived as voiced and those targets perceived as voiceless. The non-parametric Wilcoxon test was carried out to determine any significant differences in the F1OT of those /pə/ targets perceived as voiced and those /pə/ targets perceived as voiceless for subject N6 . The results of this analysis are shown in table 4.37 below. All F1OT measurements are in ms.

The results of this analysis show that there is a significant difference between F1OT duration of those target stop consonants that were perceived as voiced and those target stops consonants that were perceived as voiceless, suggesting that the perceptually based analysis was accurate in distinguishing between voiced and voiceless production.

Target syllable	/pə/						
	Perceived as voiced			Perceived as voiceless			
	Mean F1OT	Range	SD	Mean F1OT	Range	SD	Significance Level
Subject							
N6	3.00	0.00-6.00	4.24	32.10	10.00-62.00	16.77	$p < 0.001$
P1	13.60	9.00-18.00	3.51	37.60	18.00-60.00	12.81	$p < 0.001$
P3	7.16	1.00-15.00	3.08	-	-	-	-
P7	8.05	0.00-18.00	3.40	-	-	-	-
Target syllable	/tə/						
	Perceived as voiced			Perceived as voiceless			
	Mean F1OT	Range	SD	Mean F1OT	Range	SD	Significance Level
Subject							
N14	15.00	13.00-17.00	2.83	34.57	17.00-55.00	9.82	$p < 0.001$
P1	16.64	8.00-24.00	7.33	26.06	13.00-42.00	10.51	$p < 0.001$
P3	13.39	6.00-30.00	4.96	-	-	-	-
P5	16.77	6.00-39.00	6.26	24.71	9.00-34.00	9.66	$p < 0.001$
Target syllable	/kə/						
	Perceived as voiced			Perceived as voiceless			
	Mean F1OT	Range	SD	Mean F1OT	Range	SD	Significance Level
Subject							
N6	13.00	10.00-15.00	2.45	50.36	21.00-80.00	10.21	$p < 0.001$
P1	16.00	8.00-31.00	7.53	29.71	12.00-48.00	12.63	$p < 0.001$
P3	10.66	0.00-16.00	4.30	-	-	-	-
P5*	9.27	5.00-28.00	5.21	20.82	10.00-43.00	10.21	$p < 0.001$

* This subject produced the target with voicing and velar fronting

Table 4.37 Results of the F1OT analysis of the DDK trials perceived as voiced

The mean F1OT values of the stop consonants in the monosyllabic sequences perceived as voiced had short duration while those perceived as voiceless had long duration. Whilst this measure is not exactly the same as VOT values, they can be compared to VOT values where the targets perceived as voiced have short lag while the targets perceived as voiceless have long lag times. Adult VOT values for a voiced stop tend to be under 20ms in duration, while for voiceless stops between 30 ms and 120ms (Daniloff, Shuckers and Feth 1980:208). In the examples analysed in the current investigation, the mean F1OT value for a stop perceived as voiceless did not fall below 20ms and the mean F1OT value for a stop perceived as voiced did not exceed 20ms. The range of F1OT values produced by the P children of the stops perceived as voiced falls within the range of VOT values of the stops perceived as voiceless. This was not found to be the case with the N children in this analysis.

For each of these N and P subjects, the realisation of the stop targets as the voiced cognate was not always associated with fast DDK rates for all their productions, though they were within the upper end of the range of their own groups.

4.5.3 Error analysis of the bisyllabic DDK task

As with the monosyllabic sequences, fewer P children were able to produce the sequence accurately than N children. The error patterns of the transcribed bisyllabic sequences were therefore also defined in the three categories as the monosyllabic sequences : correct production, production predictable on the basis of single word and connected speech patterns, and production unpredictable on the basis of single word and connected speech patterns. Figures 4.55 and 4.56 below show the results of this analysis for the two groups of children.

As with the monosyllabic error analysis, correct productions are shown in dark blue, predictable errors in light blue and non-predictable errors in red.

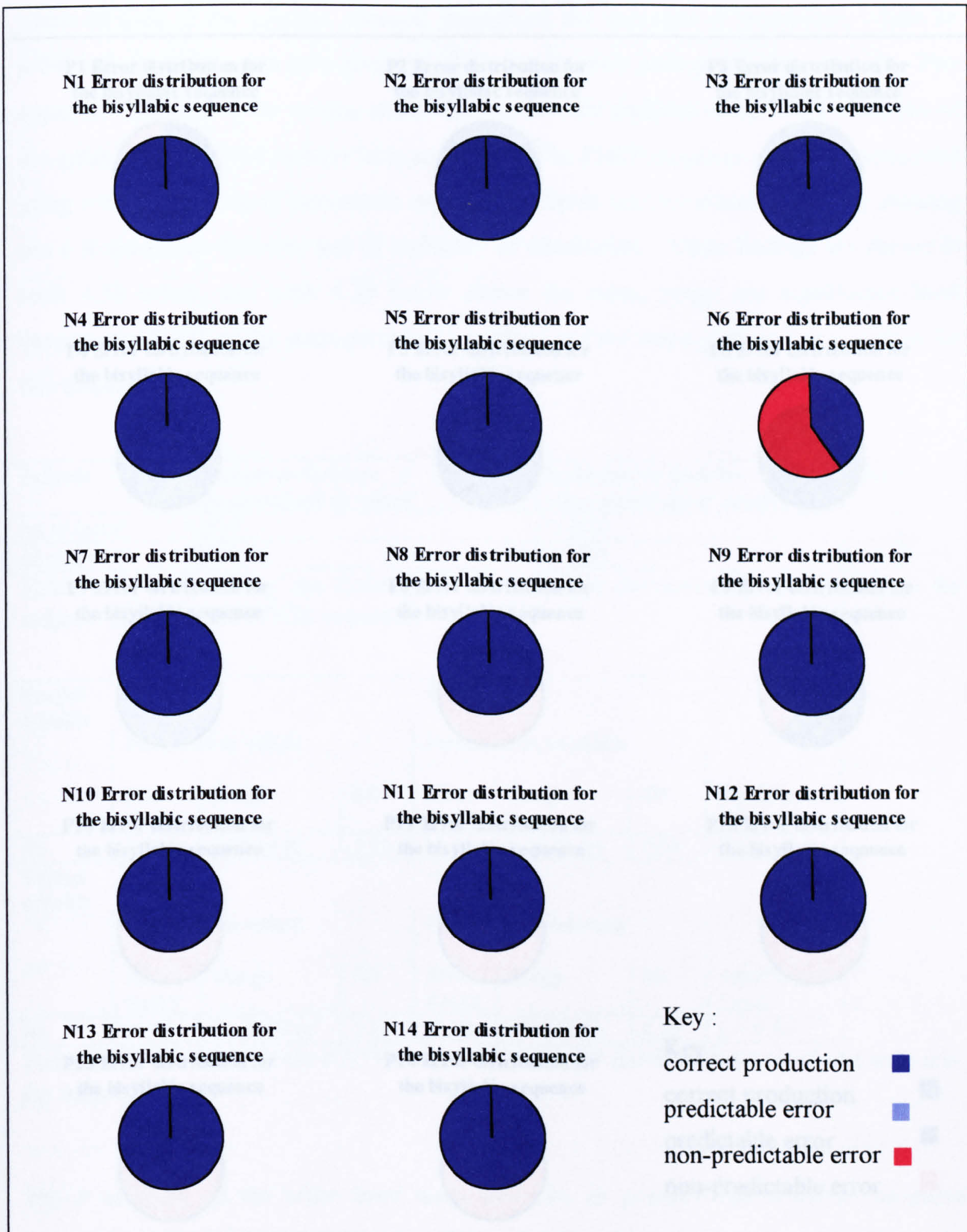

Figure 4.55 Pie charts showing the proportion of correct, predictable and non-predictable productions of /pətə/ in each of the N children

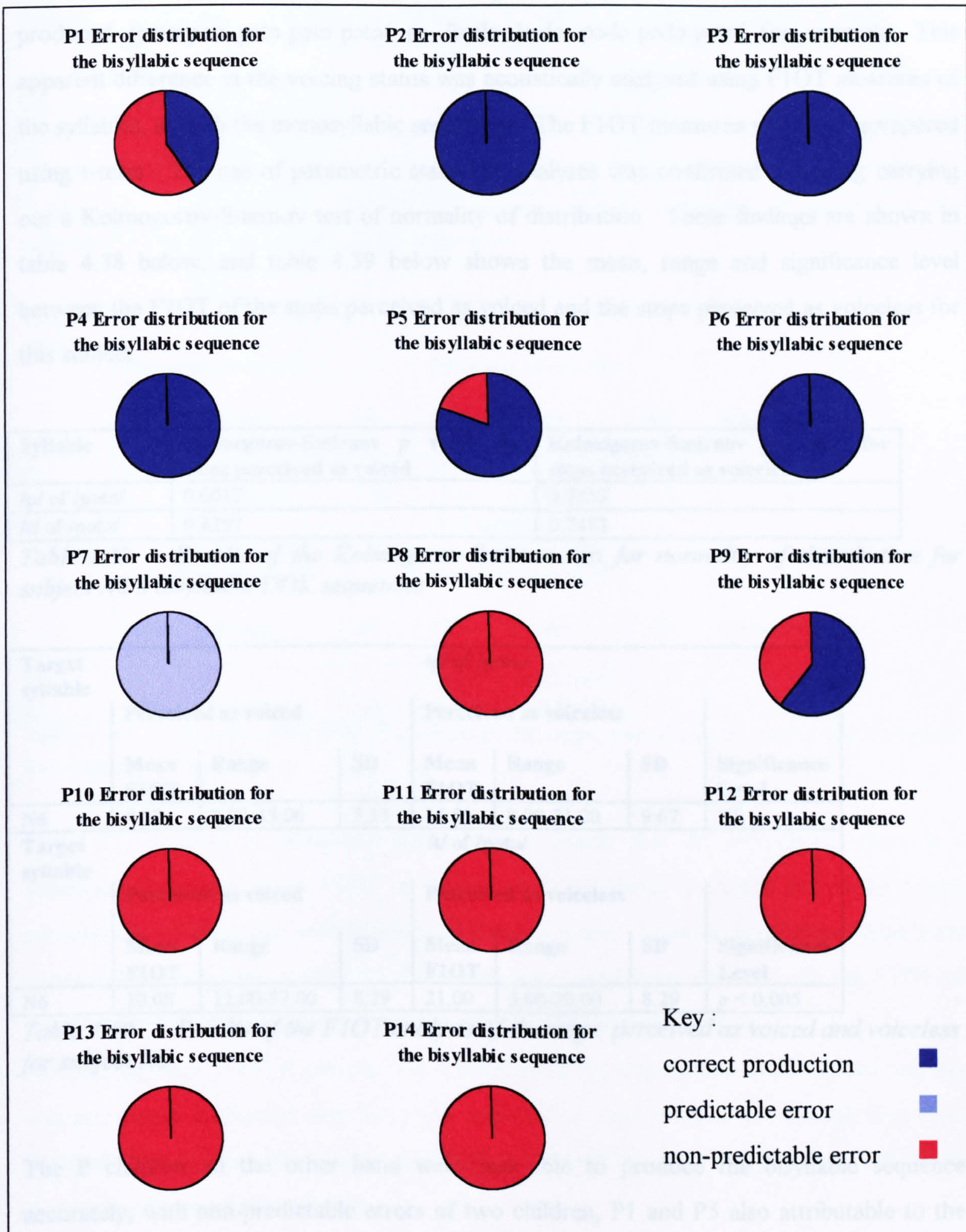

Figure 4.56 Pie charts showing the proportion of correct, predictable and non-predictable productions of /pətə/ in each of the P children

These figures show that only one N child made an error in producing the bisyllabic sequence (N6). This same child made a similar error in his productions of the monosyllabic syllable /pə/, where he voiced the bilabial stop. In his bisyllabic productions, the perceived voicing status of each of the syllables changed throughout the sequence of repetitions, where he produced /pətə pətə pətə pətə pətə/ as /bədə bədə pədə pədə pətə/ for example. This apparent difference in the voicing status was acoustically analysed using F1OT measures of the syllables, as with the monosyllabic sequences. The F1OT measures were then compared using t-tests. The use of parametric statistical analyses was confirmed following carrying out a Kolmogorov-Smirnov test of normality of distribution. These findings are shown in table 4.38 below, and table 4.39 below shows the mean, range and significance level between the F1OT of the stops perceived as voiced and the stops perceived as voiceless for this subject.

Syllable	Kolmogorov-Smirnov p value for stops perceived as voiced	Kolmogorov-Smirnov p value for stops perceived as voiceless
/p/ of /pətə/	0.6017	0.7953
/t/ of /pətə/	0.8292	0.7452

Table 4.38 Results of the Kolmogorov-Smirnov test for normality of distribution for subject N6's bisyllabic DDK sequences

Target syllable	/p/ of /pətə/						
	Perceived as voiced			Perceived as voiceless			
	Mean F1OT	Range	SD	Mean F1OT	Range	SD	Significance Level
N6	9.27	2.00-15.00	5.33	15.56	8.00-31.00	9.67	NS
Target syllable	**/t/ of /pətə/**						
	Perceived as voiced			**Perceived as voiceless**			
	Mean F1OT	**Range**	**SD**	**Mean F1OT**	**Range**	**SD**	**Significance Level**
N6	10.08	12.00-37.00	8.29	21.00	5.00-20.00	8.29	$p < 0.005$

Table 4.39 Results of the F1OT analysis of the stops perceived as voiced and voiceless for subject N6

The P children on the other hand were less able to produce the bisyllabic sequence accurately, with non-predictable errors of two children, P1 and P5 also attributable to the perceived voicing status of the stop consonant. The results of the Kolmogorov-Smirnov test for normality of distribution and the results of the F1OT analysis of these stop consonants, for two of the subjects, P1 and P5 are shown in tables 4.40 and 4.41 respectively.

Subject	Syllable	Kolmogorov-Smirnov p value for stops perceived as voiced	Kolmogorov-Smirnov p value for stops perceived as voiceless
P1	/p/ of /pətə/	0.5063	0.6128
P1	/t/ of /pətə/	0.9331	no data
P5	/p/ of /pətə/	0.6213	0.4167
P5	/t/ of /pətə/	0.5431	0.9493

Table 4.40 Results of the Kolmogorov-Smirnov test for normality of distribution for subjects P1 and P5's bisyllabic DDK sequences

Target syllable	/p/ of /pətə/						
	Perceived as voiced			Perceived as voiceless			
	Mean F1OT	Range	SD	Mean F1OT	Range	SD	Significance Level
P1	9.7	6.00-15.00	3.02	21.4	8.00-40.00	9.46	$p < 0..001$
P5	7.5	7.00-9.00	1.00	19.04	10.00-30.00	6.11	$p < 0..001$
Target syllable	**/t/ of /pətə/**						
	Perceived as voiced			**Perceived as voiced**			
	Mean F1OT	**Range**	**SD**	**Mean F1OT**	**Range**	**SD**	**Significance Level**
P1	-	-	-	25.08	12.00-49.00	8.55	-
P5	7.00	5.00-7.00	2.83	19.64	15.00-34.00	4.76	$p < 0..001$

Table 4.41 Results of the F1OT analysis of the stops perceived as voiced and voiceless for subjects P1 and P5

The F1OT analysis in table 4.41 above shows clearly that for subject P5, there is a significant difference in the F1OT of those targets perceived as voiced and those targets perceived as voiceless for both bilabial and alveolar stops. None of the alveolar stops were perceived as voiced for subject P1, but there was a significant difference in the F1OT of those bilabial stops perceived as voiced and those perceived as voiceless.

For each of these N and P subjects, the realisation of the stop targets as the voiced cognate was not always associated with fast DDK rates for all their productions, though they were within the upper end of the range. A group summary of the error analysis described above is shown in figures 4.57 and 4.58.

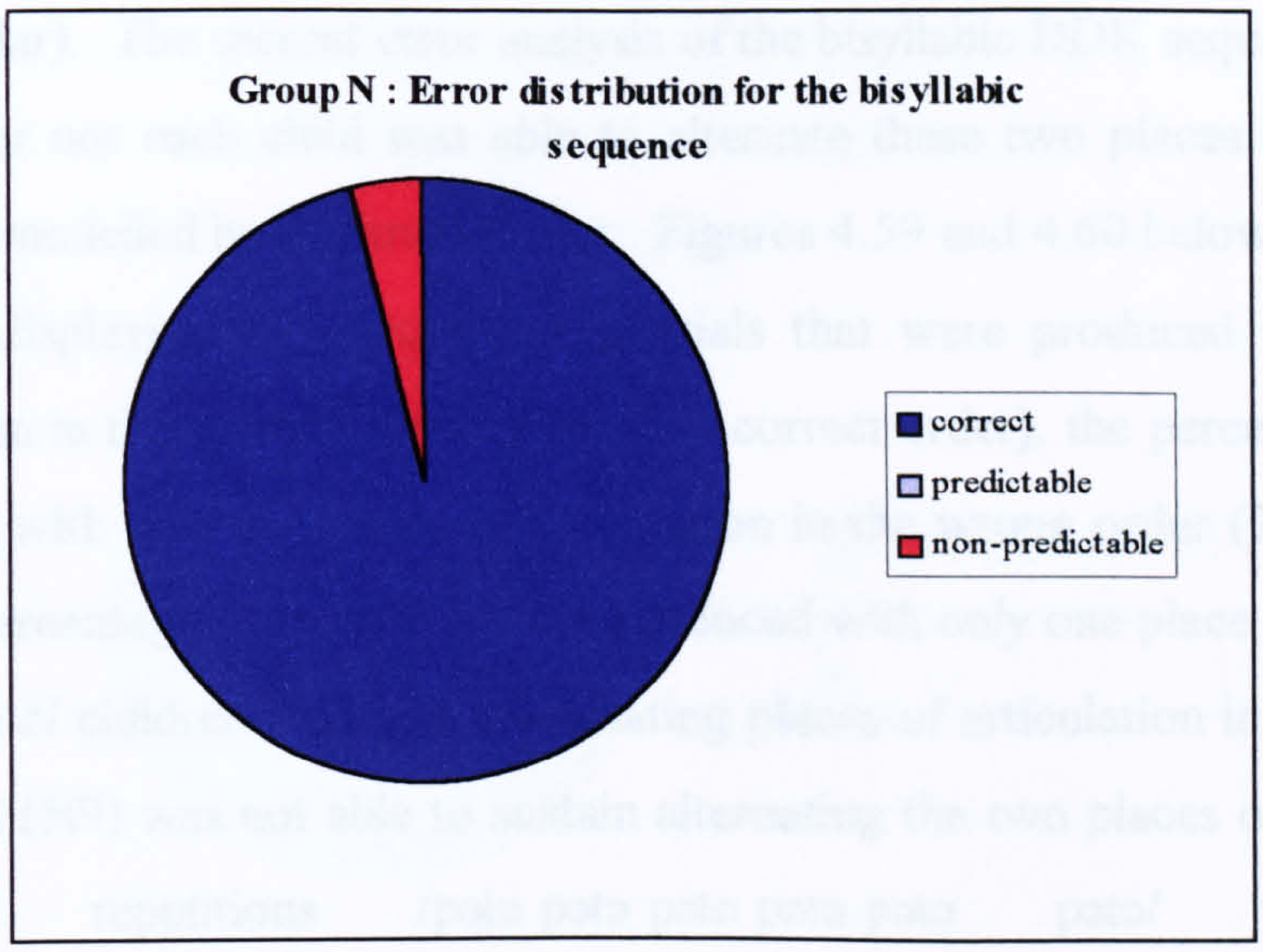

Figure 4.57 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the bisyllabic DDK repetitions for Group N

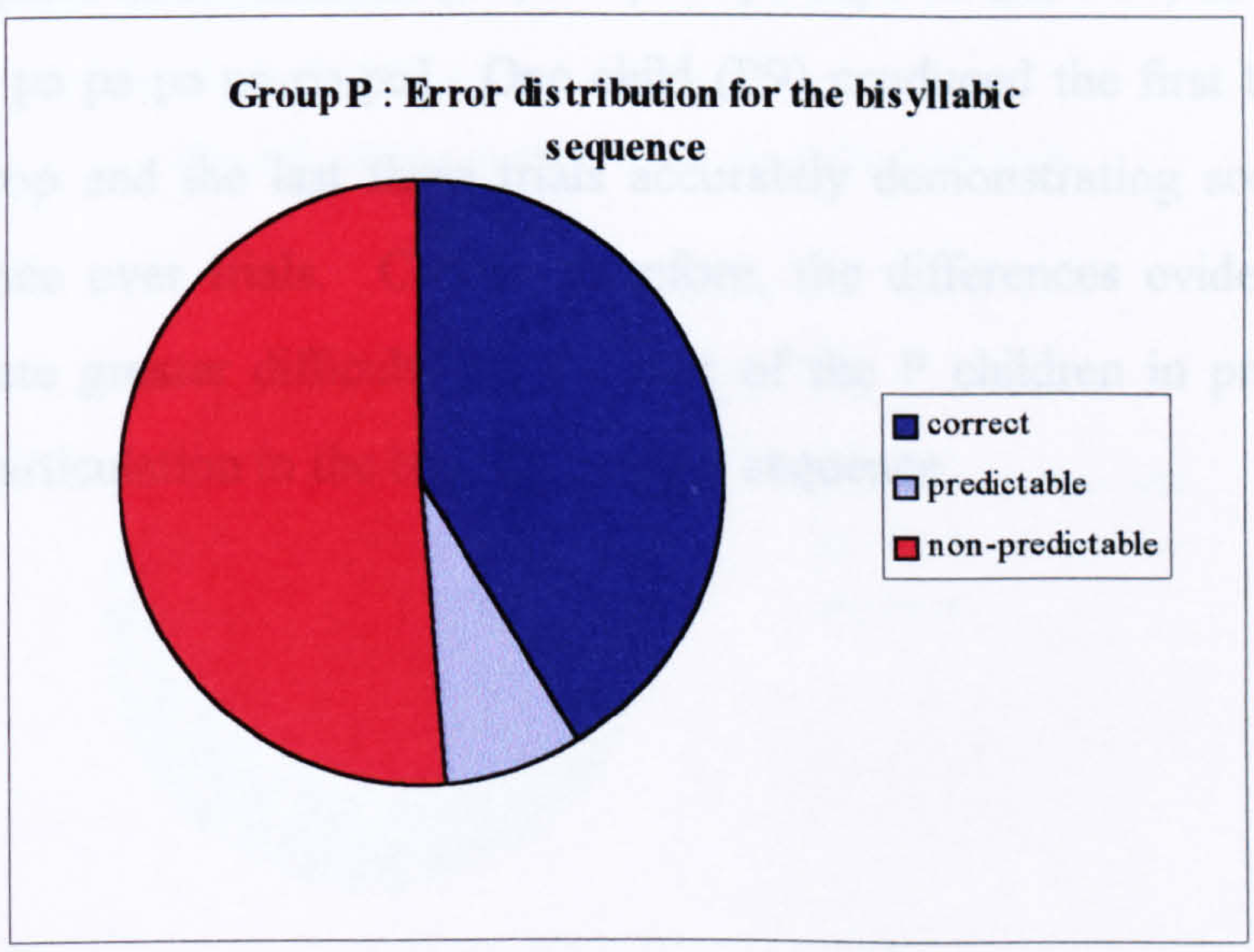

Figure 4.58 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the bisyllabic DDK repetitions for Group P

These figures show quite clearly the difference between the two groups in the proportion of non-predictable errors produced by the P children. Only a small proportion (from one child, P7) of errors can be explained by the developmental speech patterns of that child. However, the perceived voicing status does not account for all of the non-predictable errors produced by the P children. Therefore a further analysis of the errors produced was undertaken.

The bisyllabic DDK task requires the speaker to alternate two places of articulation (bilabial and alveolar). The second error analysis of the bisyllabic DDK sequence involved observing whether or not each child was able to alternate these two places of articulation as in the sequence modelled by the investigator. Figures 4.59 and 4.60 below show the results of this analysis, displaying the percentage of trials that were produced with the two places of articulation in the correct order (2 places - correct order), the percentage of trials that were produced with the two places of articulation in the wrong order (2 places - wrong order), and the percentage of trials that were produced with only one place of articulation (1 place). All of the N children made two alternating places of articulation in the bisyllabic sequence. One child (N9) was not able to sustain alternating the two places of articulation, where the modelled repetitions /pətə pətə pətə pətə pətə pətə/ was produced as [pətə pətə pəpə pəpə pətə pətə] for one of his five trials.

The P children on the other hand had greater difficulty producing the two alternating places of articulation as in the model given. Six children consistently produced the repetition using only one place of articulation (P8, P10, P11, P12, P13 and P14) as in [tə tə tə tə tə tə tə tə] or [pə pə pə pə pə pə pə pə]. One child (P9) produced the first two trials using only the bilabial stop and the last three trials accurately demonstrating some aspect of improving performance over trials. Clearly therefore, the differences evident in the figures below demonstrate greater difficulty on the part of the P children in producing two alternating places of articulation in the bisyllabic target sequence.

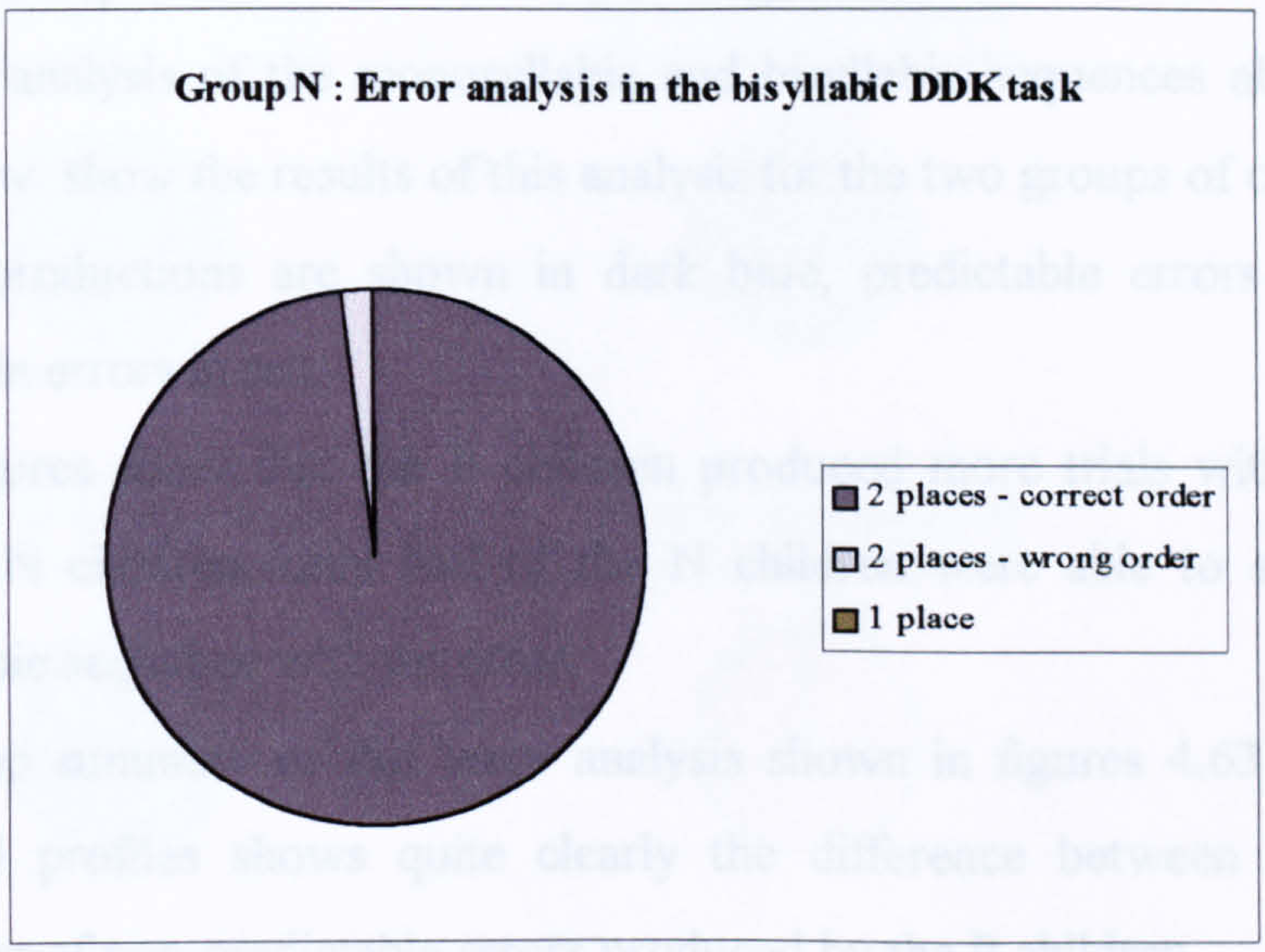

Figure 4.59 Pie chart showing the proportion of errors produced in the bisyllabic sequences by the N children

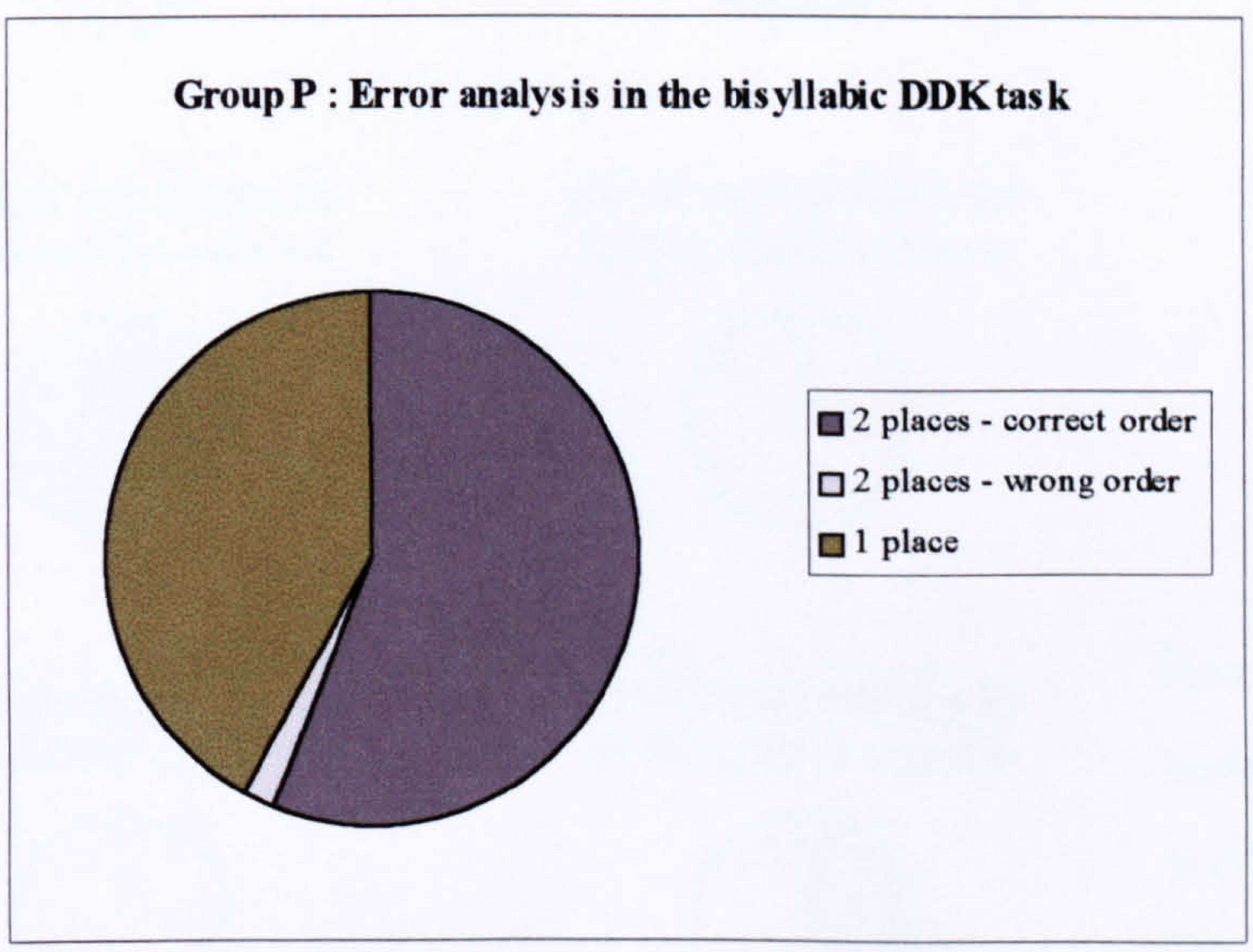

Figure 4.60 Pie chart showing the proportion of errors produced in the bisyllabic sequences by the P children

4.5.4 Error analysis of the polysyllabic DDK task

Only one P child was able to produce the polysyllabic DDK sequence accurately (in one trial only). The N children were better able to perform this task. The error patterns of the transcribed polysyllabic sequences were defined in the three categories, correct production,

production predictable on the basis of single word and connected speech patterns, and production unpredictable on the basis of single word and connected speech patterns used in the error analysis of the monosyllabic and bisyllabic sequences above. Figures 4.61 and 4.62 below show the results of this analysis for the two groups of children.

Correct productions are shown in dark blue, predictable errors in light blue and non-predictable errors in red.

These figures show that the P children produced more trials with non-predictable errors than the N children, only half of the N children were able to successfully produce the polysyllabic sequence without error.

The group summary of this error analysis shown in figures 4.63 and 4.64 following the individual profiles shows quite clearly the difference between the two groups in the proportion of non-predictable errors produced by the P children.

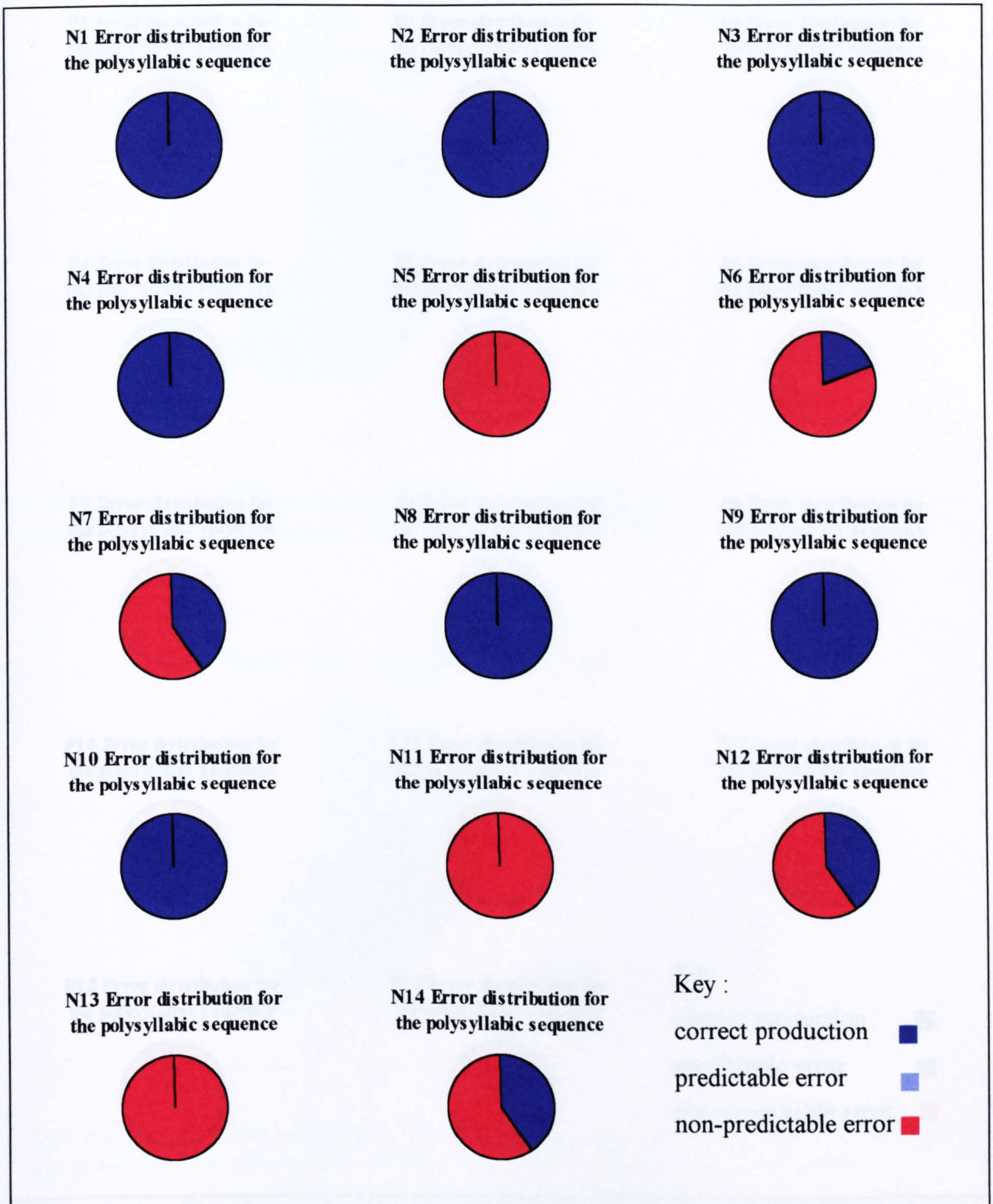

Figure 4.61 Pie charts showing the proportion of correct, predictable and non-predictable productions of /pətəkə/ in each of the N children

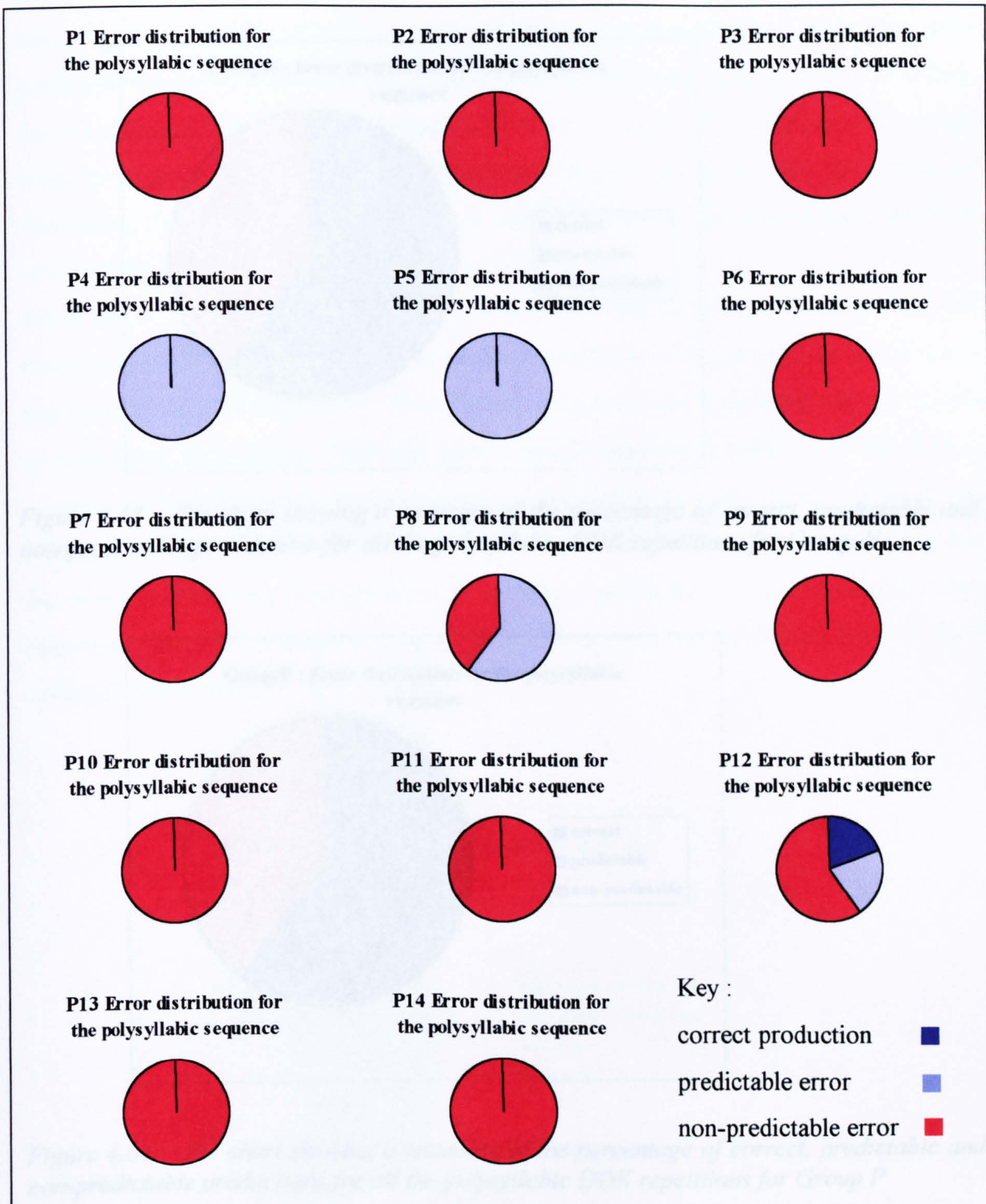

Figure 4.62 Pie charts showing the proportion of correct, predictable and non-predictable productions of /pətəkə/ in each of the P children

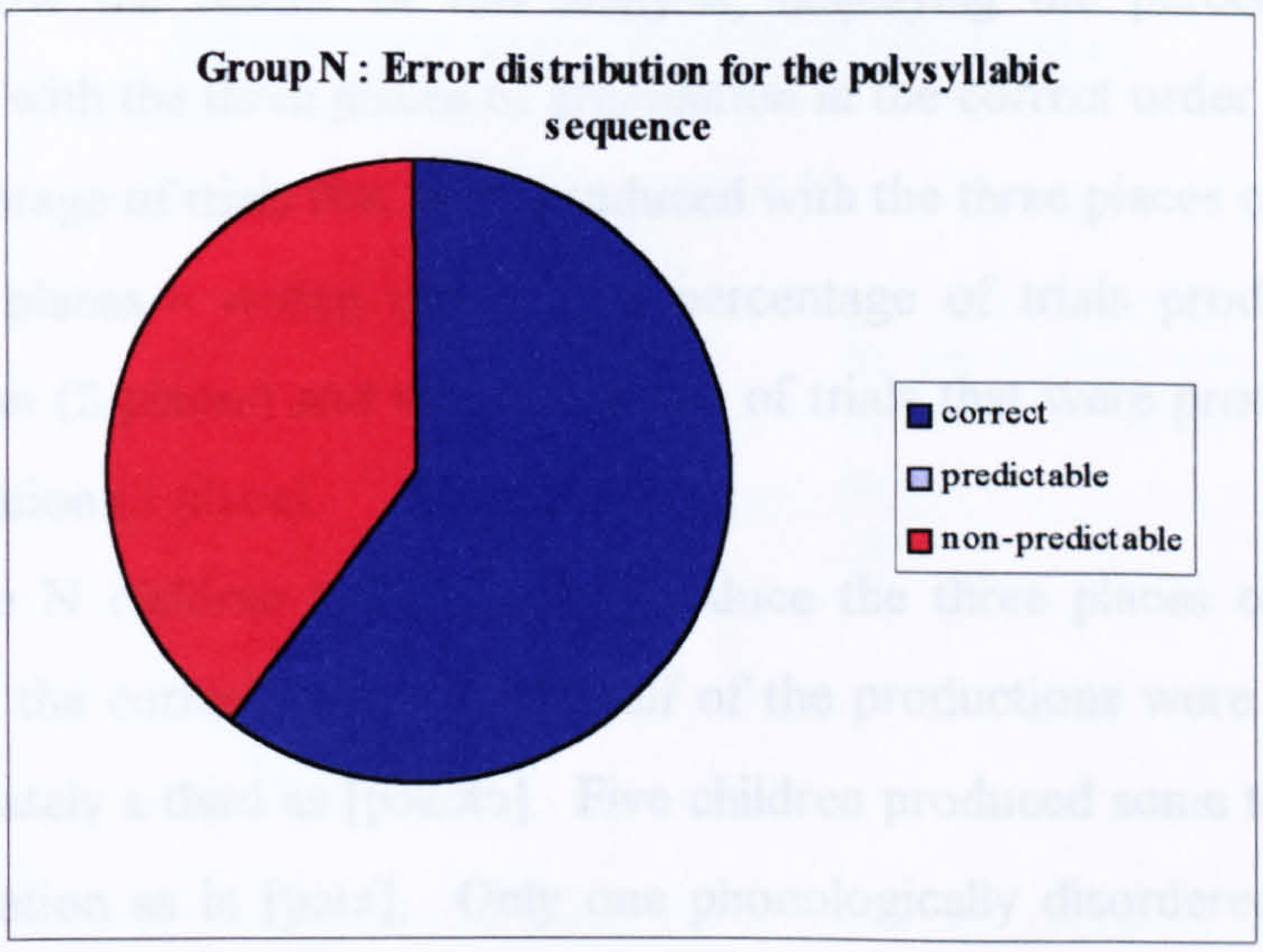

Figure 4.63 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the polysyllabic DDK repetitions for Group N

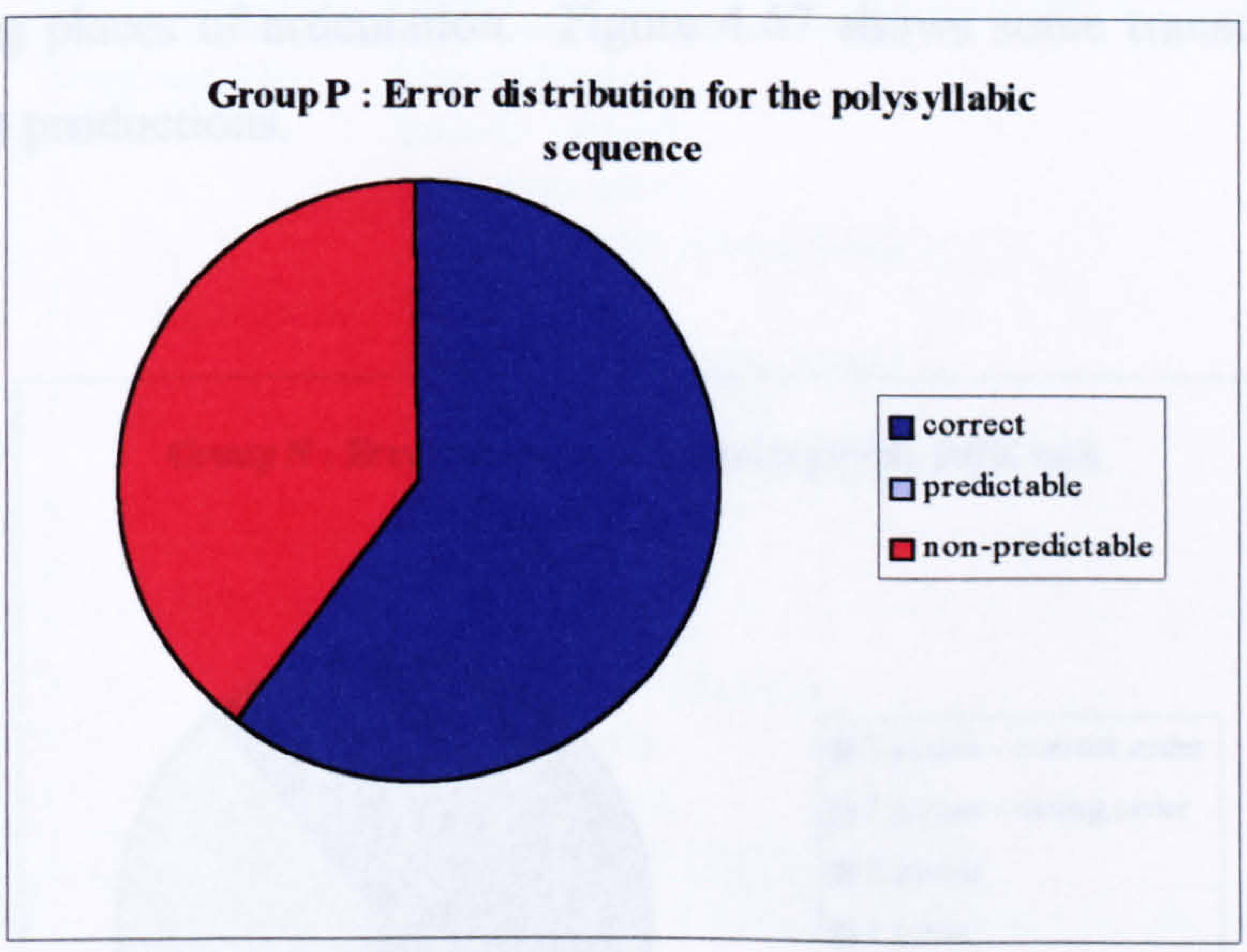

Figure 4.64 Pie chart showing a summary of the percentage of correct, predictable and non-predictable productions for all the polysyllabic DDK repetitions for Group P

Inspection of the transcribed utterances revealed that, unlike the monosyllabic and polysyllabic sequences, there was less evidence of errored production of the polysyllabic sequences involving simply voicing the target stop consonant. Rather, the difficulties facing the children was in managing to produce all three of the syllables in the sequence of repetitions. Some of the syllables contained targets perceived as voiced, and some as voiceless, however identification of a clear pattern was not possible. Therefore, a second error analysis was carried out investigating the abilities of each group of children to alternate three places of articulation (bilabial, alveolar and velar). Figures 4.65 and 4.66 below show the results of this analysis, displaying the percentage of trials that were produced with the three places of articulation in the correct order (3 places - correct order), the percentage of trials that were produced with the three places of articulation in the wrong order (3 places - wrong order), the percentage of trials produced with two places of articulation (2 places) and the percentage of trials that were produced with only one place of articulation (1 place).

All of the N children were able to produce the three places of articulation, though not always in the correct order. Over half of the productions were produced as [pətəkə] and approximately a third as [pəkətə]. Five children produced some trials using only two places of articulation as in [pətə]. Only one phonologically disordered child (P12) was able to produce one trial alternating the three places of articulation as in the model. Two of this child's trials contained the three places of articulation in the wrong order as in [pəkətə], and the others only two places of articulation. A large proportion of P children produced two alternating places of articulation. Figure 4.67 shows some transcribed examples of the P children's productions.

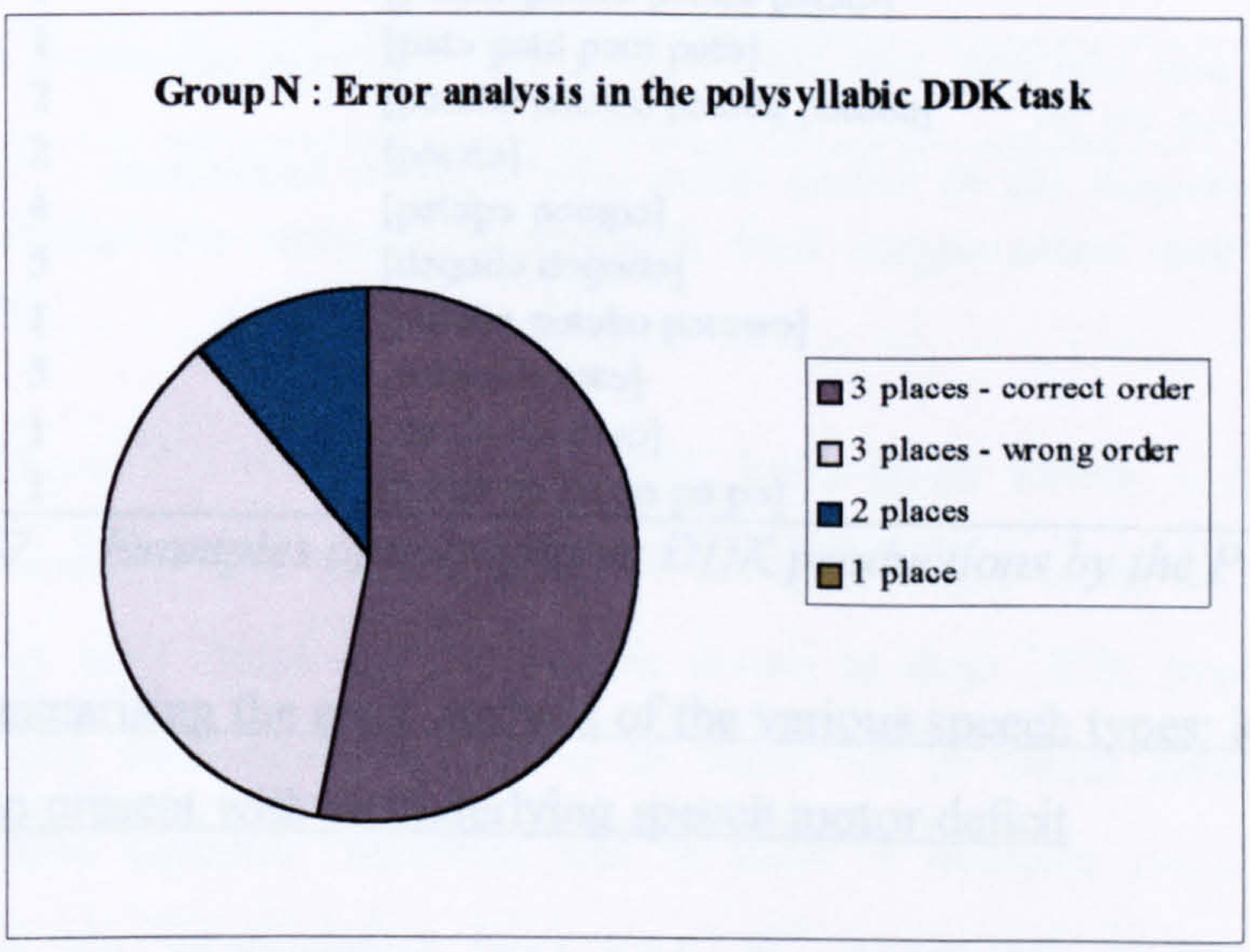

Figure 4.65 Pie chart showing the proportion of errors produced in polysyllabic sequences by the N children

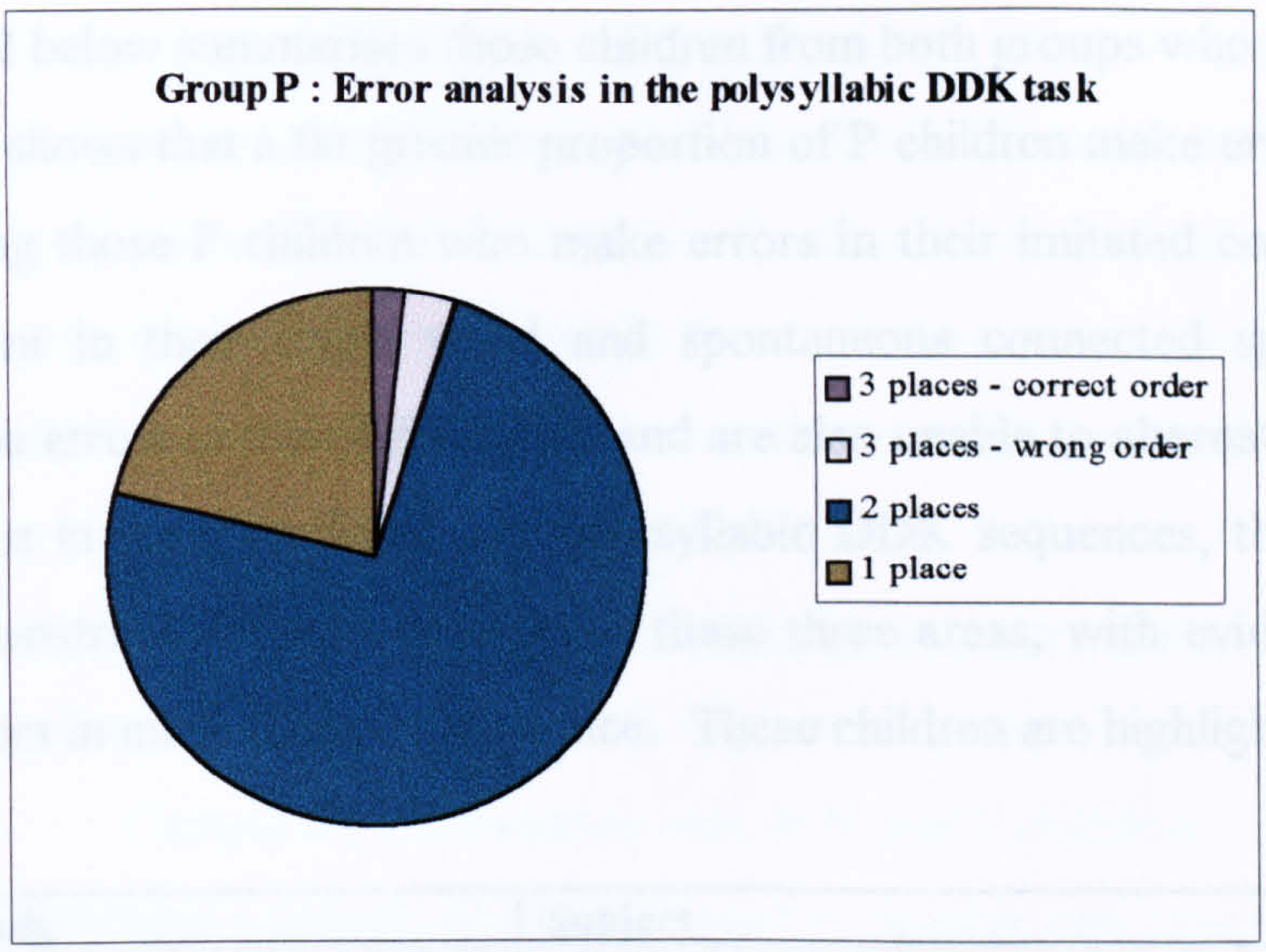

Figure 4.66 Pie chart showing the proportion of errors produced in the polysyllabic sequences by the P children

Subject	Example of polysyllabic sequence production	
	Trial number	**Transcription**
P1	1	[pətədə pətədə]
P2	3	[pətə pətə pətə]
P3	3	[pətəpə pətəpə pətəpə pətəpə]
P4	1	[pətətə pətətə]
P5	1	[pətətə pətətə pətətə pətətə]
P6	1	[pətə pətə pətə pətə]
P7	2	[pətəbə pətəbə pətəbə pətəbə]
P8	2	[pətətə]
P9	4	[pətəpə pətəpə]
P10	5	[dəgədə dəgədə]
P11	1	[pətəbə pətəbə pətəwə]
P12	5	[bətətə bətətə]
P13	1	[də də də tə tə]
P14	1	[pə pə pə pə pə pə pə]

Figure 4.67 Examples of polysyllabic DDK productions by the P children

4.5.5 Summarising the error analysis of the various speech types: identifying P children who present with an underlying speech motor deficit

The preceding sections highlighted the presence of a number of simplification processes in the individual children's imitated utterances that were not present in their single word and spontaneous connected utterances. A number of children also made errors in their DDK productions that were not predictable on the basis of their single word and connected speech abilities. Similarly, a number of children show evidence of difficulty alternating two or three places of articulation as the model in the bisyllabic and polysyllabic DDK tasks. Table 4.42 below summarises those children from both groups who make such errors.

The table shows that a far greater proportion of P children make errors than N children. In considering those P children who make errors in their imitated connected speech that are not present in their single word and spontaneous connected speech, who make non-predictable errors in their DDK tasks and are also unable to alternate two or three places of articulation in their bisyllabic and polysyllabic DDK sequences, there are several children who demonstrate difficulty in each of these three areas, with evidence of non-predictable DDK errors in more than one sequence. These children are highlighted in the table in red.

Speech task	Subject
Imitated connected speech	N7, N12 P1, P2, P3, P4, P5, P7, P8, P10, P11, P14
DDK task: /pə/	N6 P1, P3, P7, P13
DDK task: /tə/	N14 P1, P5, P14
DDK task: /kə/	N6 P1, P3, P5, P14
DDK task: /pətə/	N6 P1, P5
DDK task: /pətəkə/	P1, P2, P3, P6, P9, P10, P11, P12, P13, P14
DDK task: sequencing /pətə/	N9 P8, P10, P11, P12, P13, P14
DDK task: sequencing /pətəkə/	N2, N5, N6, N7, N11, N12, N13, N14 P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14

Table 4.42 Individual subjects who make errors in the imitated connected speech and DDK tasks that are not also present in their single word and spontaneous connected speech data

These children, P1, P3, P5, P7 and P14, each make errors in their imitated connected speech utterances that are not present in their single word or spontaneous connected speech, they each make non-predictable errors in their DDK productions, and they each have difficulty alternating two (P14) or three (all of them) places of articulation. The analyses taken together therefore, can be used to describe what may be a subgroup of children in the investigation who have an underlying speech motor deficit. This interpretation is discussed in chapter five, section 5.4.1.

4.6 Chapter summary

This chapter has presented the findings of the current investigation. The main findings of the investigation are summarised below. Section 4.6.1 summarises those results that are relevant to the hypothesis and research questions formed in chapter one and section 4.6.2 summarises those results that are relevant to the research questions formed in chapter two.

4.6.1 Summarising the results relevant to the hypothesis and research questions

4.6.1.1 *Comparing articulation rate in N and P children*

The hypothesis and research questions stated in chapter one concerned comparing the two groups of children on a number of measures of speech motor skill. All the children in the investigation presented with language skills that were not less than 6 months below their chronological age as tested using the RDLS (Reynell 1985) and the RAPT (Renfrew 1988). The P children had significantly lower scores on the RDLS (Reynell 1985) and the grammar section of the RAPT (Renfrew 1988), indicating that as a group, while their skills were age appropriate, P children tend to have poorer overall language skills than N children. The two groups of children were highly significantly differentiated on the standard scores of the EAT (Ingram et al 1971). The phonological profiles of the children devised from the single word and connected speech samples confirmed this group difference.

The P children had significantly slower articulation rate than the N children in seg/s ($p < 0.05$) and after excluding the identified outlier P3 in syll/s ($p < 0.05$) in the imitated connected speech data.

A similar finding was observed in the spontaneous connected speech sample, where the P children tended to have significantly slower articulation rates than N children in seg/s ($p < 0.05$) and after excluding the identified outlier P3 in syll/s ($p < 0.05$).

Additionally, the imitated connected speech utterances tended to be produced at a faster articulation rate than the spontaneous connected speech utterances for most of the P and N children. Analysis of the error patterns in the imitated utterances revealed that a number of P children, and some N children, exhibited error patterns in their imitated utterances that were not present in their single word or spontaneous connected speech patterns.

A relationship between measuring articulation rate in syll/s and seg/s was found to exist in both groups of children, where an increase in rate in syll/s was commensurate with a corresponding increase in rate in seg/s. However, the P children produced a fewer number of segments / syllable than the N children in both connected speech contexts. Thus the measure seg/s was deemed the most reliable indicator of articulation rate in children with developing speech patterns, where articulation rate is evaluated on the time taken to produce a number of segments and not the time taken to produce a variety of syllables that may or may not contain structural simplification processes.

The imitated connected speech sample was produced by most children in both groups at a faster articulation rate than the spontaneous connected speech sample. No relationship between the measures in the two connected speech contexts was evident, where articulation rate on one task is not necessarily predictive of articulation rate on another.

4.6.1.2 *Comparing DDK rate in N and P children*

The P children did not have slower DDK rates than the N children when DDK rate was derived from all attempts at the repetition tasks. When only the accurate attempts were used to derive a rate measure, there was also no significant difference between the two groups of children with the exception of the syllable /kə/. However, far fewer P children were able to produce the DDK syllables accurately and the analysis of the error patterns produced in the DDK sequences yielded findings which distinguished between the two subject groups.

However, by eliminating inaccurate productions DDK rate decreased in monosyllabic sequences for both groups P and N and increased in bisyllabic sequences for the P children

While the P children made a greater proportion of errors on their DDK productions, these errors could not always be explained on the basis of the phonological skills of the children as assessed in their single word and connected speech data. These children exhibited a large proportion of non-predictable errors in their DDK productions that represented error patterns that were not present in any of the children's real word speech contexts. These non-predictable errors tended to consist mainly of realisations of the voiceless stop targets which were perceived as their voiced cognate in the monosyllabic sequences. This was confirmed through measuring the F1OT of the stop consonants produced by those children whose stop consonants in the DDK repetitions had been perceived as voiced.

Additionally, the P children were less able to alternate two and three places of articulation in their bisyllabic and polysyllabic sequences than their normally developing peers.

4.6.1.3 *The relationship between articulation rate and DDK rate*

The findings of the investigation show no evidence of a relationship between articulation rate and DDK rate. That is articulation rate in a connected speech utterance is not predictive of DDK rate nor vice versa.

4.6.1.4 *Identifying P children with an underlying speech motor skills deficit*

The combined results of the error analyses revealed that there were five P children in the current investigation who presented with error patterns in the imitated connected speech, monosyllabic, bisyllabic and polysyllabic DDK sequences. In chapter five, section 5.4.1, the presence of these error patterns in each of these five children is discussed in relation to their underlying speech motor skills.

The findings of the investigation are discussed in the following chapter.

Chapter Five Discussion and Conclusions

The final chapter of the thesis contains discussion of and conclusions drawn from the findings reported in the preceding chapter. This discussion is presented in the following sections, the first (section 5.1) of which discusses those results which tend to refute the hypothesis that a group of phonologically disordered pre-school children will exhibit poorer speech motor skills than their normally developing peers, as evidenced by measures of DDK rate and articulation rate in spontaneous and imitated connected speech data. Section 5.2 discusses those results that support this hypothesis, while section 5.3 discusses the results of the investigation in relation to the specified research questions that are supplementary to the hypothesis. Section 5.4 discusses the results in relation to the development of a protocol for the collection and analysis of articulation rate and DDK rate as a tool for identifying those phonologically disordered children who have an underlying speech motor skill deficit. Section 5.5 evaluates the investigation in terms of current psyholinguistic theory. A critical review of the investigation is presented with directions for future research in section 5.6 and section 5.7 draws together the discussion of the results in the conclusions of the investigation.

5.1 Discussion of the results that tend to refute the hypothesis

The review of the literature in chapter one discussed the value of using rate measures of speech as an indication of maturity of speech motor skill. DDK rate and articulation rate have both been shown to increase with age using studies of cross-sectional design (e.g. Fletcher 1972, Walker et al 1992). Similar studies of speech disordered children show that they have slower DDK rates (e.g. Towne 1994) and slower articulation rate than their normally developing peers. (e.g. Waters 1992 showed that articulation rate of imitated connected speech was significantly slower in phonologically disordered children than in their normally developing peers when measured in seg/s). However, differences in methodologies made it difficult to draw firm cross study conclusions.

This review led to the hypothesis that a group of phonologically disordered pre-school children would have poorer speech motor skills than a group of their normally developing peers as evidenced by measures of DDK rate and articulation rate in imitated and spontaneous connected speech.

There are findings in the reported investigation that refute this hypothesis. This evidence lies in the DDK data, where the P children studied did not have significantly slower DDK rates than their N children. This is contrary to the findings reported by McNutt (1977), Henry (1990) and Towne (1994) where phonologically disordered children did have significantly slower DDK rates than their normally developing peers.

In the current investigation, when DDK rate is derived from repetitions of the syllable sequences (inaccurate as well as accurate), as is assumed in the investigations reported by McNutt (1977) and Henry (1990), none of the rates measured for the P children were significantly slower than those of the N children. When only accurate repetitions are considered in the rate calculation, as with Towne (1994), no significant difference was found for the monosyllables /pə/ and /tə/, the bisyllable /pətə/ and the polysyllable /pətəkə/. The fact that a significant difference exists between the two groups of children for the DDK rate of the accurately produced velar sequence /kə/ is of interest in the light of the other findings. This finding, which in fact supports the hypothesis is discussed in section 5.2 below, however it should be pointed out that the validity of the statistical difference can be questioned due to the fact that far fewer P children were able to produce this sequence accurately.

The overall finding that P children do not have significantly slower DDK rates raises two interesting points. It can be surmised either that the P children do not present with an underlying speech motor skill deficit, or that DDK rate is not a sensitive measure of this type of deficit. Based on DDK rate alone it can be speculated that the P children, who do not have significantly slower repetition rates in a maximum performance task, do not therefore have a speech motor component contributing to their speech production difficulties. Arguments in support of the assertion that DDK rate alone is not a sensitive measure of speech motor skill are presented in section 5.2 below.

The results comparing the articulation rate measures of the two groups of children provide conflicting evidence with regard the acceptance or rejection of the hypothesis. When the complete data sets are considered, the P children do not have significantly slower articulation rates than the N children in both the imitated connected speech and the spontaneous connected speech when measured in syll/s. However, a statistical outlier was identified in the P group (subject P3), and on eliminating this outlier from the analysis, the difference between the two groups reached significance. The former finding may be considered as refuting the hypothesis, where it can be interpreted either that there is no evidence of an underlying speech motor deficit in the P children as a group, or that articulation rate alone is not a sensitive and robust measure of this skill. The findings of previous research do indicate that articulation rate is a valid indication of speech motor skill, and when the statistical analysis is carried out after removing the outlier P3 , the difference between the mean articulation rates of the two groups reaches significance. This finding, which supports the hypothesis is considered in section 5.2 below.

5.2 Discussion of the results that support the hypothesis

There are a number of findings that can be interpreted as supporting the hypothesis: that is the P children as a group evidenced slower mean articulation rates and slower mean DDK rates than the N children, though the difference between the two groups did not always reach statistical significance. Additionally, while the DDK rate measures do not indicate any significant difference between the two groups of children, it is clear from the error analysis reported in chapter four that the P children perform differently from the N children in the same tasks. The evidence presented in the reported investigation does indicate that there are aspects of children's performance on imitated connected speech and DDK tasks that can reveal differences in the underlying speech motor skills of N and P children, and that rate measures on their own are not a sufficient indication of speech motor ability.

These two issues are discussed in the following section, with articulation rate in the imitated and spontaneous connected speech data considered first followed by the results of the error analysis of children's performance on the imitated connected speech and DDK tasks.

As pointed out above, the P children tended to have slower articulation rate in both seg/s and syll/s in both connected speech contexts than their normally developing peers. The level of statistical significance of this finding varies due to the presence of an outlier in the P group. When this outlier, who presented with lax articulation that was difficult to segment, were removed from the statistical analysis, a significant difference between the N and P children's articulation rate values in both seg/s and syll/s was found for both connected speech contexts. Calculation of articulation rate in seg/s in both connected speech contexts yields a more significant difference than calculation in syll/s. In the imitated connected speech sample, when excluding the outlier, the difference between the means for the two groups of children when measured in seg/s reached significance at $p < 0.05$ ($p = 0.012$) while when measured in syll/s significance is reached at $p < 0.05$ ($p = 0.025$). In the spontaneous connected speech sample, the difference between the two groups' means for the measure in seg/s is significance at $p < 0.003$ and for syll/s at $p < 0.05$. Thus it can be concluded that segmental articulation rate is a more robust measure of the articulation rates in the two groups of children, particularly in spontaneous connected speech data. This finding supports that of both Walker et al (1992) and Waters (1992), supporting the notion proposed by Waters (1992) suggesting that P children produce fewer segments in the same unit time than N children in imitated utterances due to immaturity of the speech motor mechanism.

It could be argued that the fact that there was a tendency for the P children to have slower syllabic and segmental articulation rate in the imitated speech is in itself indicative of poorer speech motor skills. Because the P children produced the imitated utterances with reduced syllabic structure (evidenced by the finding that the P children have fewer segments/syllable than the N children) then they should be able to produce these utterances at a faster rate, since they contain fewer articulatory gestures. If the P children have speech motor skills no less mature than their normally developing peers, (i.e. if the disordered speech output is the result of linguistic/cognitive constraints alone) then they might be expected to have faster articulation rates (in syll/s) than the N children measured over the same utterances. This was not in fact the case in the reported data, and this finding tends to support the hypothesis. Table 5.1 below shows the transcription of the utterance "two naughty boys are picking" with the number of syllables, number of segments and total articulating time for each utterance.

Subject and utterance code	Transcription	No. of syllables	No. of segments	Total articulating time (ms)
P2 im7	[u nɔ bʷɔɪ ɪ pɪ]	5	9	1465
N1 im4	[tʰu nɔti bɔɪz ər pʰɪkɪŋ]	7	17	1950

Table 5.1 Transcription of the utterance "two naughty boys are picking" for subjects P2 and N1 showing the total number of syllables, total number of segments and total articulating time for each.

The articulation rate for P2's utterances was calculated as 3.41 syll/s and 6.14 seg/s and for N1's utterance the articulation rate was calculated as 3.59 syll/s and 8.72 seg/s. Thus, where P2 reduces the content of his syllables by producing fewer segments, his articulation rate in syll/s is only slightly slower than N1's who produces all the segments of the utterance as the adult target. If there were no motor constraints acting on P2's speech production the expectation would be for the articulation rate in syll/s to be faster as he is producing fewer articulatory gestures. The fact remains that this child needed as much time as the normally developing child to produce fewer articulatory gestures. Thus, it can be concluded that a measure of articulation rate in seg/s yields more robust data than measuring articulation rate in syll/s.

A further finding from the articulation rate data in the current investigation is that for both measurements syll/s and seg/s, the group mean articulation rate in the imitated connected speech is faster than in the spontaneous connected speech, in both groups of children. Individually this is also the case for most of the children where the imitated connected speech tends to be produced with faster articulation rate than the spontaneous connected speech. (Only two disordered children have faster articulation rate in the spontaneous speech condition in both measures seg/s and syll/s, while one disordered and one normally developing child have faster articulation rate in the spontaneous speech condition in only one of the rate measurements taken). This finding is contrary to that of Walker et al (1992) where spontaneous articulation rate was found to be faster. Walker et al (1992) suggest two possible reasons for their finding, firstly the articulation rate of the modelled utterance may affect the rate of speech produced by the children and secondly the degree of care and attention the children use in imitating a given utterance may influence rate. Both of these reasons are relevant in interpreting the findings of the current investigation. Walker et al (1992) presented the imitated utterances using slowed speech, mimicking that of young children, and it seems likely that the children produced their utterances in imitation to this, where they too slowed down their own utterances, producing the imitated utterances at an articulation rate slower than that of their spontaneous utterances. In the current investigation, the model given to the children was presented at the normal rate of the adult experimenter. It is possible therefore that the children could have attempted to produce the imitated utterances in a similar time frame to that of the model, leading to articulation rates that were faster than found in their spontaneous utterances.

The modelled utterances were presented to the children at a mean articulation rate of 4.45 syll/s, the mean articulation rate for the N children in imitation was 4.25 syll/s while for the P children this was 3.95 syll/s. Mean spontaneous articulation rates for the two groups of children are approximately half a syllable per second slower than mean imitated articulation rate, indicating that the habitual articulation rate of the two groups of children was slower than the imitated articulation rate produced in the investigation. This finding can be interpreted using the argument above. If it is the case that the children were trying to produce their imitated utterances in a similar time frame to the model resulting in increased imitated articulation rate, then the finding that the N children were more able to produce the utterances in an adult time frame than the P children further supports the hypothesis. (This observation is discussed further in relation to the relationship between articulation rate in the imitated and spontaneous connected speech samples in section 5.3.2 below.)

However, in attempting to achieve this shorter time frame for producing the imitated utterances, the children, and especially the P children, seem to sacrifice accuracy, including reducing syllable structure, leading to a slower articulation rates in seg/s. The finding that the number of segments produced per syllable for the imitated speech was significantly less than the number of segments produced per syllable for the spontaneous speech, for both groups of children, indicates that in producing the utterances in a shorter time frame, the number of achievable gestures reduces. The stimulus utterance did not however contain a high degree of segments/syllable in the adult form.

Additionally, some of the children produce systemic and structural simplification errors in their imitated connected speech that are not present in their single word and spontaneous connected speech data. Eleven of the P children produced the imitated utterances with simplification processes not evident elsewhere in their speech production patterns, while only two N children made similar unanticipated errors. This can be interpreted to be a direct consequence of increasing speed, with the P children less able to cope with the demands of increased speed of production than the N children.

The most notable type of "forced error" (that is, an error which is forced upon the child as a result of producing the utterance in a shorter time frame) was present in the P children in the deletion of the final consonant /z/ of the word "boys". Seven P children, including the fastest child P3, deleted this consonant, none of whom presented with this simplification process in their single word data or spontaneous connected speech. However, this type of error may also reflect difficulty at another level - that is the children may not be able to signal the plural /z/ and may not in fact be deleting that final consonant in the imitated utterance. However, evidence from the data collected using the RAPT (Renfrew 1988) indicates that these children do not have this morphological difficulty, where they indicated the plural morpheme where appropriate.

N12, P2 and P14 used context sensitive voicing (where the [t^h] of the word "two" was produced as the voiced [d]). N7 stopped the word final fricative /z/ of the word "boys", P5 devoiced the word final fricative /z/ of the word "boys", and P1 backed the alveolar stop /t/ of the word "naughty". The presence of these errors in utterances which were produced with a faster articulation rate than in the children' spontaneous connected speech, implies that in increasing speed the children forgo accuracy, with the P children less able to retain accuracy when increasing their articulatory speed than the N children. The N children produced fewer of these forced errors which tends to support the hypothesis that as a group, they have more mature speech motor skills than the P children.

The imitated task was not however deliberately designed to elicit faster speech from the children. The finding that the children did have faster articulation rates in the imitated utterances than in their spontaneous utterances, and the fact that this was contrary to the results reported by Walker et al (1992) led to the above conclusion being reached.

The DDK task on the otherhand was explicitly designed to elicit the fastest possible productions of a series of syllable sequences. The effect of asking the children to produce the DDK syllables as fast as they possibly can was found to further reduce the ability of the P children to produce these non-word syllable sequences accurately - where fewer P children produce the sequences accurately than N children.

In the one DDK task where there was a significant difference between the two groups of children for the DDK rate for accurate productions of /kə/, the P children were significantly slower. It can be argued in this case that where the children have aimed for and achieved accuracy, they do so by compromising speed. However, since the number of P children who could accurately produce this syllable was far smaller than N children, the validity of the statistical significance comes into question.

Abnormal performance on DDK tasks has been highlighted by Westbury and Dembowski (1993) as indicative of the inability of the speaker to optimise the articulatory movements required for the DDK task, at least in normally speaking adult speakers. Thus, the presence of more errored productions in the P children can be construed as indicating an underlying speech motor deficit. Furthermore, there is evidence from the analysis of the errors produced in the DDK tasks to support the argument that forced errors occurring in this test of maximum performance are the result of poorer speech motor skills. In collecting the DDK data from the children, there was an expectation that there would be a number of mispronunciations produced by both groups of children, but more so by the P children who exhibit many more speech sound errors in all the data samples.

This expectation was based on the premise that the P children would mispronounce the syllables using the same systemic simplification processes as in their single word and connected speech. This type of performance on the DDK tasks could indicate that the underlying difficulty facing the children stemmed from their phonological rule system, where they produce all types of speech output, meaningful or not, applying the same rules to their production. If these were the only error types found in the DDK data from the P children, then they might be indicative only of phonological level difficulties (notwithstanding the putative non-linguistic nature of DDK tasks) and therefore give no information about the status of these children's speech motor skills. This type of error, which was found in some of the data, was defined as an error that was predictable on the basis of the child's single word and connected speech patterns. However, there were examples where the error produced was not found in the child's single word and connected speech patterns, and as such not indicative of only a phonological level difficulty. These errors were defined as non-predictable, as they could not be interpreted as arising from rules the child habitually applies to his/her speech output. It can be inferred therefore that these additional errors in maximum performance conditions stem from a speech motor limitation rather than from a phonological constraint.

The transcribed data supports this theory further, where the P children make a far greater proportion of non-predictable errors on the monosyllabic sequences than the N children. These non-predictable errors on the whole consisted of the voiceless stop consonant being realised as voiced. The subsequent F1OT analysis of these initial stop consonants in the CV sequences supported the initial perceptual identification, and shows that the stop consonants concerned were in fact produced with shorter durations, similar to the short voicing lag associated with the VOT values of initial voiced stop consonants.

The evidence presented by Macken and Barton (1980), in their study of the acquisition of the voicing contrast in American English, indicates that at the earlier stages of development both voiced and voiceless stops are produced with short lag (i.e. as the voiced cognate), and gradually the voiceless stops are produced with long lag, until a perceptual distinction is detectable. While the P children in the reported investigation are older than those studied by Macken and Barton (1980), they show that they have acquired the voicing distinction in the phonological / perceptual analysis of their single word and connected speech productions. When faced with the demands of the DDK task, they appear to be unable to sustain this distinction, and produce the target voiceless stop as voiced, exhibiting what can be construed as a forced error. This type of error can be interpreted as an indication of poorer speech motor skill in the P group.

In the analysis of the bisyllabic and polysyllabic sequences, aside from the mispronunciations that would be predicted to occur in the data gathered from the P children, it was clear that other factors were influencing performance in these syllable sequences also. Where none of the N children had any difficulty alternating two places of articulation in the bisyllabic repetitions, five P children had this difficulty. In the polysyllabic sequences, where nine of the N children could alternate three places of articulation, only one P child was able to produce this sequence producing three places of articulation.

These differences highlight the effect of the increased demands being placed on the P children when faced with the DDK repetitions in comparison to the N children. If the P children did not have any motor constraints on their speech production systems, then the findings would show that they were able to alternate those places of articulation that they produce in their single word and connected speech abilities. The fact that they were unable to produce even those places of articulation present in their phonetic and phonemic inventories, shows that other constraints are taking place. This observation is supported more in the bisyllabic DDK sequence, where most of the P children were able to produce both bilabial and alveolar stops in their single word and connected speech samples. The inability to produce the added velar stop in the polysyllabic sequence may at times be interpreted as a feature of the phonological constraints in these children who produce velar stops as alveolar stops in their single word and connected speech samples. This conclusion supports Towne (1994) where the phonologically disordered children in his study had greater difficulty producing bisyllabic sequences. This study, described in chapter one section 1.3.2.2, used a bite-block technique to assess articulatory compensatory ability, and although methodologically distinct from the reported investigation, the conclusions that are reached are compatible. Where Towne (1994) proposes that at least some P children may have an underlying difficulty with speech motor control, the findings reported in the current investigation lead to the same conclusion. There is evidence from the current investigation that identifies those P children with speech motor difficulties. The findings with regard to these children, and conclusions in relation to the clinical identification of such children are discussed further in section 5.4 below.

Evidence presented by Williams (1996) and Williams and Stackhouse (1997, 1998) suggests that pre-school children's performance on DDK tasks should be analysed not only for rate but specifically by comparing the error patterns with the child's own speech capabilities on single iterations of the stimulus token. This conclusion is supported by the results of the reported investigation. The use of the DDK task, where the children are instructed to produce the syllables as fast as they can, leads a number of children, both N and P (though many more P children) to make forced errors that do not occur in their spontaneous speech patterns.

These findings indicate that analysis of how P children produce imitated utterances modelled at a faster rate than they would habitually use, and analysis of the error patterns evident in their DDK productions can be used to infer level of speech motor skills in these children. This type of information can then be interpreted to inform more adequately differential diagnosis of those P children who have speech motor constraints underlying their speech production difficulty, and thus direct more appropriate intervention.

5.3 Discussion of the results in relation to the specified research questions that are supplementary to the hypothesis

The disparity of findings reported in the literature with regard measuring articulation rate and DDK rate in young normally developing and phonologically disordered children raised a number of methodological concerns with regard the collection, analysis and interpretation of this type of data.

Following the review of the literature, two measuring techniques were used to gauge articulation rate from the two groups of children in the reported investigation - that of seg/s and syll/s. A significant relationship between these two measures has been shown in N children (Walker et al 1992). The relationship between the two measures in P children was tested in the current investigation.

Two types of speech data were also gathered, both imitated and spontaneous connected speech samples. Walker et al (1992) found an increase in articulation rate of both imitated and spontaneous connected speech associated with maturation in N children. Thus the relationship between measuring articulation rate in the two connected speech contexts was investigated in both the groups of N and P children in the current investigation.

Additionally, there was contradictory evidence with regard the relationship between articulation rate and DDK rate (Haselager et al 1991, Yaruss et al 1994), in normally developing Dutch speaking and normally developing and dysfluent American English speaking children.

The question of similar relationships existing in normally developing and phonologically disordered Scottish English speaking children was raised, and the data collected in the reported investigation used to investigate this.

Discussion of the findings relating to each of these points follows in the sections below.

Possible explanations for the differences in the findings reported in the literature were highlighted in chapter two, where a number of methodological concerns were raised in comparing the various published studies. Further discussion of the reported investigation in relation to these concerns follows below.

5.3.1 Relationship between articulation rate in seg/s and syll/s

The finding by Walker et al (1992) that there is a significant correlation between measuring articulation rate in syll/s and seg/s across two age groups of N children has been replicated here in both the N and P children. The main conclusion that can be drawn from this outcome demonstrates that the two measures are essentially interchangeable. Thus, it should be appropriate for an investigator to select either measure as a valid indication of articulation rate and therefore draw conclusions from this data regarding the speaker's speech motor skills.

In the reported investigation the relationship between the two measures was tested, and it was found that the correlation was sufficiently high to infer that both can be used as a reliable indication of speech motor skill. However, using the example given previously in section 5.2, the value of this relationship can be questioned. The articulation rate of P2's imitated utterances was 3.41 syll/s and 6.14 seg/s. An imitated utterance produced by N1 yielded an articulation rate of 3.59 syll/s and 8.72 seg/s. Thus while the measures for each child in syll/s are similar, the reduced syllabic structure evident in P2's production yields a slower articulation rate in seg/s. The syll/s measure does not, in this case, reveal much of value about P2's production of the utterance. Until, that is, the transcription is inspected demonstrating precisely how different the utterances are. Furthermore there is evidence indicating that vowel length changes occur depending on the nature of the following consonant in adult speech. Munhall, Fowler, Hawkins and Saltzman (1992) show that adult speakers tend to shorten or lengthen the vowel preceding singleton and clustered consonants to maintain syllable duration. Thus, where a syllable contains fewer segments (as in VC compared to VCC for example), there is a tendency for the overall syllable duration to be similar in both examples. Therefore, it can be argued that syllabic articulation rate is not an effective means of determining the number of articulatory gestures achieved per unit time in connected speech patterns.

Thus measuring articulation rate in seg/s allows for a more accurate calculation for both groups of children. This conclusion is reached on the basis that articulation rate in seg/s measures more precisely the rate with which different children produce articulatory gestures in connected speech.

5.3.2 Relationship between articulation rate in the imitated and spontaneous connected speech samples

Previous research has shown that the articulation rate of both imitated connected speech and spontaneous connected speech increase with maturity (Walker et al 1992). The finding that a high articulation rate in both speech contexts may indicate that there is some relationship between the two, and articulation rate on one may be a predictor of articulation rate on the other. The findings of the current investigation do not show that there is a relationship between the two measures and that a relatively fast rate in one does not necessarily predict a relatively fast rate in the other.

However, it was pointed out in chapter two that for a valid comparison to be made between the articulation rates of the two connected speech contexts, both contexts should contain utterances of equal or similar length. In the reported investigation, the mean lengths of the spontaneous connected utterances were somewhat longer than the imitated connected speech utterances, in both groups of children.

It is widely accepted that there is a relationship between articulation rate and utterance length (Malécot et al 1972, Amster 1984). What constitutes a long utterance and a short utterance is however unclear. Of those studies which have collected connected speech data from children, Walker et al (1992) define a short utterance as one which contains less than 6 syllables and a long utterance contains more than 6 syllables. Both Amster (1984) and Haselager et al (1991) on the other hand define a short utterance as one ranging between 2 and 4 syllables, a medium length utterance as one ranging between 5 and 7 syllables and a long utterance as one over 8 syllables in length.

In the reported investigation, utterances ranged from a mean length of 4.50 syllables to a mean length of 9.25 syllables, indicating that the utterances analysed were of medium-long duration as per the definitions proposed by Amster and Haselager et al above.

In developing the method for the current investigation, attempts were made to control for these utterance lengths. The findings reported in chapter four, section 4.3.3, do reveal some differences between the two groups of children in utterance length. These findings show that the N children tended to produce longer spontaneous utterances than the P children, while for both groups of children all the spontaneous connected utterances tended to be slightly longer than the imitated connected utterances.

These differences in utterance length may account for the finding indicating no relationship between the articulation rate of the spontaneous connected speech and the articulation rate of the imitated connected speech.

However, it was of greater interest to note that the imitated utterances were produced at a faster articulation rate than the spontaneous utterances. Differences in utterance length do not account for this as the children did not produce the imitated utterances faster because they were longer. The imitated utterances were in fact slightly shorter than the spontaneous utterances. Thus it can be surmised that they were produced at a faster rate because of the instruction given (as discussed above in section 5.2).

In using a slowed adult articulation rate in their modelled utterances, giving the children in their investigation a model comparable to the children's own rates, Walker et al (1992) may have effected a slowing down in the imitated sample compared with the children's habitual rates. Support for this lies in the interpretations the children make of the instruction to "imitate what they heard". That is they have been able to detect that the modelled utterances were produced slower than they would have expected from an adult speaker. It can be speculated therefore that the instruction could have been interpreted by the children to imitate what they heard, and in recognising that the modelled rates were slowed adult rates, they too produced slower rates.

This argument, together with the evidence that young N and more particularly P children make more forced errors in the imitated utterances than the spontaneous utterances lends itself to the conclusion that in collecting and analysing this type of data in children, we should present them with a normally produced adult model and compare the articulation rates in these imitated utterances with their own habitual articulation rate from spontaneous connected speech data. The resultant rate measure together with an analysis of the level of articulatory accuracy can provide information regarding the underlying speech motor capabilities of that child. This combination of quantitative measurement with qualitative analysis of the data provides far more information about children's speech production abilities.

5.3.3 Relationship between articulation rate and DDK rate

In the current investigation, no correlation was found to exist between articulation rate (in either the imitated or spontaneous connected speech data) and DDK rate. This finding supports that of Haselager et al's (1991) study of normally developing Dutch children, but refutes that of Yaruss et al's (1994) study of normally developing and dysfluent American children. These studies compared spontaneous articulation rate using different methodologies and this may account for the disparity in findings. For example, Haselager et al (1991) calculated a DDK rate from a number of different CV syllables, while Yaruss et al (1994) calculated DDK rate from a number of different CVCVCV syllables. In the current study. the correlation was calculated between the mean DDK rate for accurately produced trials of each monosyllabic, bisyllabic and polysyllabic sequence.

There is however little to indicate that the two measures are related. Whereas the DDK task is a test of maximum performance and the child is instructed to produce the syllables as fast as possible, in both the imitated and spontaneous connected speech tasks the children were not instructed to speak at any particular rate. While both the N and P children did produce their imitated speech faster than their spontaneous speech, this was not demanded of them. One measure cannot therefore be used as a predictor of the other.

The information that can be gleaned from the two types of data can however be taken together to give insight into the underlying difficulties of children with a phonological disorder.

5.3.4 Discussion with regard to the methodological issues raised in chapter two

In this section, the methodological issues raised in chapter two are reconsidered in the light of the reported investigation. Specifically, experimental design in relation to connected speech data, DDK data, data collection, analysis and interpretation and the subjects used in the investigation are considered.

5.3.4.1 *Connected speech data*

By controlling the stimuli used in collecting the spontaneous connected speech data, many of the children produced similar spontaneous utterances in terms of content (i.e. describing the video cartoon). The most difficult aspect of collecting spontaneous speech is that it is often the case that the utterances are short and grammatically incomplete as a feature of the communication process, and in children of this age they can be unforthcoming with information, requiring adult support and prompting at times. However, it was possible to gather suitable data for most of the children. This type of data elicitation procedure could be applied to gather data for other investigations of child speech, where the child is concentrating on the video and not their own speech, thus producing habitual and unselfconscious speaking patterns.

The imitated connected utterances elicited from the children may have been too short to compare successfully with the spontaneous utterances collected and this should be considered in any future similar investigation.

5.3.4.2 *DDK data*

The DDK data collected in the reported investigation was limited to the most commonly reported CV syllables used in previous normative studies (e.g. Fletcher 1972, Canning and Rose 1974, Robbins and Klee 1987).

There has been some debate about the value of using real words and non-words in a DDK task, where each has been shown to make different demands on the speaker (Williams and Stackhouse 1997, 1998). However, since one of the main points raised in chapter two concerned the collection and analysis of DDK data in existing published material, it was important that the reported investigation use comparable sequences to allow for improvement in the previously reported procedures for collecting and analysing this data.

5.3.4.3 *Data collection procedures. data analysis and data interpretation*

One of the most important features that differentiates the current investigation from most others, with the exception of Towne (1994), is the calculation of DDK rate from accurately produced utterances only. For most of the syllabic sequences no significant difference was found between the two groups when DDK rate was collected regardless of whether accurate productions only or all attempts at the sequence were used. It might be concluded therefore that it makes no difference which method is used. However, there are two separate observations of the data that argue otherwise. Firstly, for one of the sequences a significant difference between the N and P groups was found when accurate productions of the monosyllabic sequence /kə/ were used but not when all the data for /kə/ productions was used. However, few P children were able to accurately produce this sequence, thus depleting the sample in the statistical analysis.

Secondly, by eliminating the inaccurate trials from the analysis to calculate a DDK rate for accurate productions only, the mean group DDK rate altered. Table 5.2 below illustrates this point.

	/pə/		/tə/		/kə/		/pətə/		/pətəkə/	
	N	P	N	P	N	P	N	P	N	P
all trials DDK rate (syll/s)	4.03	3.93	4.00	3.93	3.74	3.68	4.58	4.18	3.55	3.98
accurate DDK rate (syll/s)	3.98	3.78	3.99	3.91	3.72	3.01	4.56	4.35	3.57	3.01*

* *value taken from one trial from one child only*

Table 5.2 DDK rate of each of the sequences for both groups of children. The mean group values in syll/s are given for the all the trials and for the accurate trials only.

The information in this table is interesting in a number of respects. Firstly, for the monosyllabic sequences /pə/ and /kə/ the group mean value decreases when the inaccurate trials are eliminated. This decrease is more evident in the P children than in the N children. There is a slight decrease also for the monosyllable /tə/, by less than for the other monosyllables. For the bisyllabic sequence on the other hand, while there is a slight decrease in the group mean DDK rate for the N children there is a larger increase for the P children. Thus, the process of eliminating inaccurate productions from the analysis of DDK rate clearly affects the calculation of DDK rate. Thus, it can be concluded that while overall there is no significant difference between N and P children in terms of DDK rates, it is crucial that only accurate productions are considered due to the effect this clearly has on the overall group mean values.

Additionally, when the accurate and inaccurate trials are identified, the data is then in a form for investigating the nature of any errors in the productions. This then allows the productions to be examined in relation to other aspects of the individual child's own speech output skills. This style of approach is also favoured by Williams (1996) and Williams and Stackhouse (1997, 1998), where the productions over a sequence were compared to one single iteration of the token sequence.

5.4 Towards the development of a methodologically sound protocol for the collection, analysis and interpretation of articulation rate and DDK rate, as indicators of speech motor skill, in pre-school children

One of the themes running throughout this thesis concerns the methods that can be applied to investigate speech motor skill in phonologically disordered pre-school children. There is evidence in the current investigation that can be used to identify those children with an underlying speech motor deficit. The findings of the current investigation are drawn together in identifying precisely who these children are. The results of the investigation are then considered with a view to developing a suitable protocol for the clinical identification of phonologically disordered children with a speech motor skills deficit.

5.4.1 Identifying those P children in the current investigation who have an underlying speech motor deficit

Section 4.5.5 of the results chapter presented a summary of the error analysis of the imitated connected speech utterances and the error analysis of the DDK productions. Five of the P children were highlighted as presenting with each of the following error patterns: 'forced errors' in the imitated task, non-predictable DDK errors in their monosyllabic, bisyllabic and polysyllabic sequences and difficulty alternating two or three places of articulation in the bisyllabic and/or polysyllabic sequences. Table 5.3 below summarises the error patterns present in the data collected from each of these children. The mean articulation rate of the imitated data is also shown. This measure has been given a rating shown in parentheses after the value, showing how slow or fast the production is in relation to the other children in the group, where 1 refers to the fastest and 14 refers to the slowest. All of these children produced their imitated utterances with evidence of at least one forced error.

Subject	**imitated seg/s**	**Non-predictable errors**					**Difficulty alternating two places of articulation**	**Difficulty alternating three places of articulation**
		[pə]	[tə]	[kə]	[pətə]	[pətəkə]	[pətə]	[pətəkə]
P1	7.73 (5th)	yes	yes	yes	yes	yes		yes*
P3	9.06 (1st)	yes		yes		yes		yes*
P5	8.62 (2nd)		yes	yes	yes			yes**
P7	5.84 (13th)	yes						yes*
P14	7.81 (4th)		yes	yes		yes	yes	yes**

** these children were able to produce velars in some of their single word and connected speech samples*

*** neither of these children produced a velar stop in any of their single word or connected speech samples*

Table 5.3 Table showing the imitated articulation rate in seg/s of subjects P1, P3, P5, P7 and P14, and which of the DDK error patterns they also present with, denoted by "yes"

The table shows that four of these subjects have imitated articulation rates that are among the fastest for the whole group of disordered children, resulting in forced errors in their utterances. These four children, P1, P3, P5 and P14 each produce non-predictable errors and have difficulty alternating three places of articulation. Both P1 and P3 were able to produce velars elsewhere in their single word and connected speech samples, albeit inconsistently. P5 and P14 on the other hand could not, and thus their inability to alternate three places of articulation in the DDK task may be replicated in a polysyllabic real word containing these three places of articulation. P14 also has difficulty alternating two places of articulation, both of which she could produce in her other speech data.

Subject P7, with one of the slowest imitated articulation rates among the P children also had forced errors in her imitated utterances.

In section 5.2, it was argued that the presence of forced simplification processes in the imitated utterances (which were produced at rates faster than the children employed in their spontaneous connected speech) and error patterns in the DDK tasks are each signs of speech motor limitations. However, it must be pointed out that while the hypothesis that P children, as a group, have poorer speech motor skills than their N peers was supported by the articulation rates in the spontaneous connected speech data, the children who form this tentative sub-group do not present with the slowest articulation rates as might have been expected. It seems therefore that this sub group has emerged on the basis of the error analysis in the imitated and DDK data only. However, it was suggested that the forced errors in the imitated utterances may occur as a result of the trade off between speed and accuracy. That is, these children made the forced errors as a results of producing the imitated utterances at a faster than habitual articulation rate. Thus, it can be argued that presence of an underlying speech motor deficit may be identified through investigating the trade off between speed and accuracy of production, where increased speed is associated with decreased accuracy.

The individual clinicians responsible for these children's management were contacted to discover how these children had progressed in therapy. P3 and P14 are still receiving regular speech and language therapy. Both of these children are reported to have struggled with therapy that targeted their underlying linguistic skills using a Metaphon approach to intervention. P3 is currently having difficulty blending fricatives with vowels in CV sequences without producing a stop. P14 is finding it difficult to produce velars with consistency, producing words with velars using different articulatory gestures each time. Discussion with this child's therapist indicates that P14 would be described as "inconsistent deviant" if assigned to one of Dodd's (1995) sub groups. P1 on the other hand has been discharged from therapy following successful intervention which concentrated on her metaphonological skills. There was some evidence of residual difficulties in her connected speech that she was able to correct when asked. It is possible that in this child's case there was evidence of underlying difficulties at both the motor and phonological levels. Since P5 has left the country no comment can be made about his progress.

P7 on the other hand has developed a severe stutter which is impeding her progress in phonological therapy. Therapy is currently being directed to her dysfluency. Curlee (1984:243) suggests that dysfluency may result from an "...inability to execute rapid, precise complex motor responses" and this may be the case with this child. Where there is an underlying speech motor deficit, it is manifesting as both phonological impairment and stuttering behaviour.

Inquiries as to the progress of some of the other P children in the investigation have also been made. P6 and P13 were successful with the Metaphon approach to intervention and have been discharged. P9, P10, P11 and P12 have each made progress using a wide variety of intervention procedures, and the therapist responsible for their management does not report any suspicion of underlying speech motor difficulties. Follow up information on P2 and P4 has not yet been made available. It was not possible to follow up the progress of P8 as he has left the area.

It can be concluded therefore that the measures used in the current investigation have been successful in identifying which of the P children presented with an underlying deficit with speech motor skills. Presence of forced errors in imitated speech, non-predictable errors in DDK productions <u>and</u> difficulty alternating two or three places of articulation (where they can clearly produce each of these places of articulation in other DDK data or in their single word and connected speech samples) indicates who these children are.

There is therefore some scope for clinical application of these measures in the assessment of the speech motor skills of phonological disordered children. The development of such a protocol is described in the following section.

5.4.2 <u>Development of a clinical protocol for the identification of speech motor skills deficit in phonologically disordered children</u>

The procedure used in the current investigation was able to identify a number of P children who have an underlying speech motor deficit. In the following sections this procedure is discussed with a view to developing a protocol that is appropriate for use in the clinical identification of phonologically disordered children who have an underlying speech motor deficit.

5.4.2.1 *Discussion of the procedures used in the investigation*

The protocol devised in this investigation set out to address some of the methodological issues raised elsewhere in this thesis. When collecting data from young children it is inherently difficult to maintain the balance between eliciting the required data and keeping the children stimulated enough to want to participate.

In collecting both the imitated and spontaneous connected speech data the method employed was, on the whole, successful. By using pre-recorded utterances for the imitated tasks, each child was presented with the same model and thus presentation rate was controlled. The rate of presentation was deemed to be appropriate in terms of the rate at which an adult speaks to a child, and not slowed to child's rate. Arguments in favour of not slowing presentation rate to a child's rate were discussed in sections 5.2 and 5.3.2 above.

As children are becoming increasingly aware of and interested in computer technology, the use of such computer software to assist was successful.

The cartoon used to elicit the spontaneous speech was not enjoyed by all the children, some of whom disliked the character, and thus co-operation was sometimes limited. In current trends of ever changing media popularity, this type of elicitation task will always need to be revised.

On the whole, however, these tasks are clinically appropriate and realistically achievable. Analysis of rate of the data collected on the other hand is less easy to carry out accurately without the necessary instrumental equipment, and future research may be designed to address this problem. The availability of analysis software such as Computerised Speech Lab™ or Multispeech™ systems developed by Kay Electromics Corporation may not extend to everyday clinical use. However, recently software has been developed that can be used in conjunction with these systems that can analyse rate of production relatively easily (Kay Elemetrics Corporation 1999).

The criteria specifying utterance onset and utterance offset, and for defining pause boundaries using instrumental techniques allows for an accurate - to 1ms - evaluation of total articulating time. Different boundaries have been imposed by different researches, where for example Waters (1992) in the imitated phrase "two wee boys are playing in the" measured the duration of the utterance from the release of the closure associated with the /t/ of "two" to the end of energy in the second and third formants associated with the schwa vowel in the word "the". Rate in seg/s was then calculated after determining the number of segments produced in the utterance. Haselager et al (1991) on the other hand measured the duration of various spontaneous utterances of varying lengths from an oscillographic display of each utterance. Rate was calculated for each utterance produced from the onset of the first vowel to the onset of the vowel in the final syllable, by determining the total duration and the total number of syllables less one. This procedure was used to eliminate any lengthening effects associated with the final syllable of the utterance. In the current investigation the technique used by Waters was applied to both the spontaneous and imitated samples. In data collected from young children, where they may produce medium rather than long utterances (as per the definitions described in section 5.3.2 above), further reduction of the corpus for analysis may make it difficult to achieve a satisfactory indication of rate. Thus, it is recommended that for young children, the utterance be measured from the onset of the release of the first consonant to the offset of the final consonant or vowel.

Simply measuring articulation rate in these two connected speech tasks was not the only useful outcome in relation to investigating the underlying speech motor skills of the two groups of children. The analysis of the productions the children made, and the comparison between the articulation rates for the two speech contexts allows for investigation of how the children approach each task. Where the spontaneous connected speech task gives an indication of the habitual speech performance skills of each child, the imitated task was, for most of the children, produced with faster articulation rate than their spontaneous samples. In two of the N children (N7 and N12) and eleven of the P children (P1, P2, P3, P4, P5, P7, P8, P9, P10, P11 and P14) this increase in tempo led to forced errors, whereby the children made simplification processes that were not consistent with data from their single word and spontaneous connected speech production. Thus, measuring articulation rate is not the only means by which interpretations can be made from this type of data about the children's speech motor skills.

The methodology designed for the collection and analysis of DDK data required greater definition, to take into account the lengths of time young children can maintain the repetition and the mispronunciations they produce. The data collection task itself, using the trains to elicit the syllables, was enjoyable to the children and stimulating in that the children were eager to produce more complicated strings of syllables by adding carriages to the train. The range of the number of syllables the children produced per turn was large, from three or four syllables to over twenty syllables. An analysis was carried out to determine whether or not the DDK rate calculated for longer strings differed from that of a string of up to six syllables, in both cases measuring from the end of the first syllable to the end of either the sixth or the penultimate syllable, the results of which are shown in tables 5.4 (for the N children) and 5.5 (for the P children) below. (See Appendix 10 for the mean DDK rates for each child using each measurement procedure). This analysis was carried out on the accurate productions only. No statistically significant difference was found between these two measures. Thus, it was deduced that the DDK rate produced by the children in the current investigation did not change over the course of producing the strings of syllables.

Syllable	Mean group rate from end of first to end of sixth syllable (syll/s)	Mean group rate from end of first to end of penultimate syllable (syll/s)	*P* value	Significance
/pə/	4.00	3.98	0.714	not sig.
/tə/	4.01	3.99	0.928	not sig.
/kə/	3.66	3.72	0.650	not sig.
/pətə/	4.57	4.56	0.988	not sig.
/pətəkə/	3.60	3.57	0.771	not sig.

Table 5.4 Comparison of long versus short DDK strings for the N children

Syllable	Mean group rate from end of first to end of sixth syllable (syll/s)	Mean group rate from end of first to end of penultimate syllable (syll/s)	*P* value	Significance
/pə/	3.80	3.78	0.903	not sig.
/tə/	3.95	3.91	0.902	not sig.
/kə/	3.11	3.01	0.745	not sig.
/pətə/	4.58	4.35	0.509	not sig.
/pətəkə/	2.65*	3.01*	n/a	not sig.

* This rate is not a mean value, but the rate taken from the only accurately produced /pətəkə/ sequence from the whole of group P.

Table 5.5 Comparison of long versus short DDK strings for the P children

It was pointed out in chapters one and two that any mispronunciations of the DDK data may affect rate calculation. This is because inherent differences in consonant durations may have an overall effect on the total duration of any strings of repetitions. Thus rate was calculated both on all trials of the DDK sequences and on the accurately produced trials only. However, the findings of the current investigation show no significant difference in most of the DDK rates between the two groups of children, either when rate is calculated from all attempts or from the accurate productions only. The only exception to this finding is for accurate repetitions of the syllable /kə/ where the P children had significantly slower DDK rates than their normally developing peers. Thus, the primary conclusion would tend to indicate that there is no need to account for accurate and inaccurate productions based on the evidence from the remaining DDK rate comparisons. However, there is a need for a more thorough investigation of DDK rate development in N children taking into account the mispronunciations that they may make before a definitive conclusion on their use can be made. Additionally, as pointed out in section 5.3.4.3 above, evidence in the reported investigation indicates that when eliminating inaccurate productions of DDK tokens from the calculation of DDK rate alters the rate finding.

Furthermore, the error analysis of the inaccurate DDK productions in the current investigation do show potential for use in detecting underlying speech motor difficulties in the children. Where DDK rate was not found to yield useful information about speech motor skill, the error analysis of the DDK productions was. Analysis of these DDK productions, which are demanding that children produce a series of speech-like sounds at a level of maximum performance, in terms of the children's current speech production abilities proves extremely useful. This approach is also advocated by Williams (1996) and Williams and Stackhouse (1997, 1998). How the children in the current investigation would perform with different syllables, non-words and real words cannot be ascertained, and such future research is proposed in section 5.5 below.

The results of the current investigation have given support to the view that a sub group of phonologically disordered children with an underlying speech motor deficit exist. These children were identified using all of the analyses presented. Articulation rate data from two connected speech contexts allow for a comparison of the speech production skills of a child when faced with different tasks. Where a child produces an imitated utterance at a faster tempo than spontaneously, the effect this has on the accuracy of production can be investigated. This information taken together with an error analysis of how the child performs when demanded to produce a series of syllables at as fast a rate as possible can lead to interpretations regarding that child's speech motor skills.

From the current investigation, it is proposed that the presence of each of three factors indicates an underlying speech motor deficit. Firstly, the presence of forced errors in imitated connected speech utterances that are not present in single word or spontaneous connected speech utterances, where the imitated articulation rate is faster than spontaneous articulation rate. Secondly, the occurrence of non-predictable errors in DDK syllable production. Thirdly, difficulty alternating two or three places of articulation in bisyllabic and polysyllabic DDK repetitions.

Using these three factors as the identifying elements, a protocol for clinical use can be proposed.

5.4.2.2 *Towards a clinical protocol for the identification of phonologically disordered children who have an underlying speech motor deficit*

In order to use this kind of evidence in the clinical setting, the speech and language therapist would have to collect a number of different data samples. Single word data from for example the Metaphon Screening Pack (Dean et al 1990) provides data for analysis within a phonological framework. Articulation rate, preferably in seg/s though this analysis may be less accurate in the clinical setting, from both imitated and spontaneous connected speech utterances would need to be calculated. From this, any evidence of the child speeding up in the imitated task can be evaluated. Phonological process analysis needs to be carried out to determine the presence of any forced errors in the imitated connected utterances in comparison to the single word and spontaneous connected data.

DDK data from monosyllabic, bisyllabic and polysyllabic sequences should be collected and transcribed. The nature of any mispronunciations should be evaluated in comparison to the phonological simplification processes occurring in other aspects of the child's speech output.

Thus, having collected and analysed this from a child, the speech and language therapist could make some judgement as to whether or not there is an underlying speech motor deficit playing a role in that child's phonological disorder. This information would then be used to inform management decisions.

The method described in the current investigation could be used in the clinic to collect the required information. However, there are some aspects of the current investigation that could be improved upon before its use would be advocated. Such improvements may indicate the need to replicate and extend the findings of the reported investigation with larger groups of children. Suggestions for such improvements are considered in the section 5.6 below.

5.5 An evaluation of the investigation in relation to current psycholinguistic theory

The three tasks presented to the children in the reported investigation can also contribute to understanding of the nature of children's speech processing abilities. A current model of speech processing proposed by Stackhouse and Wells (1997) is increasingly being used clinically.

This model of single word processing, provides a useful framework through which the speech and language therapist may make diagnostic and client management decisions. This model is shown in figure 5.1 below.

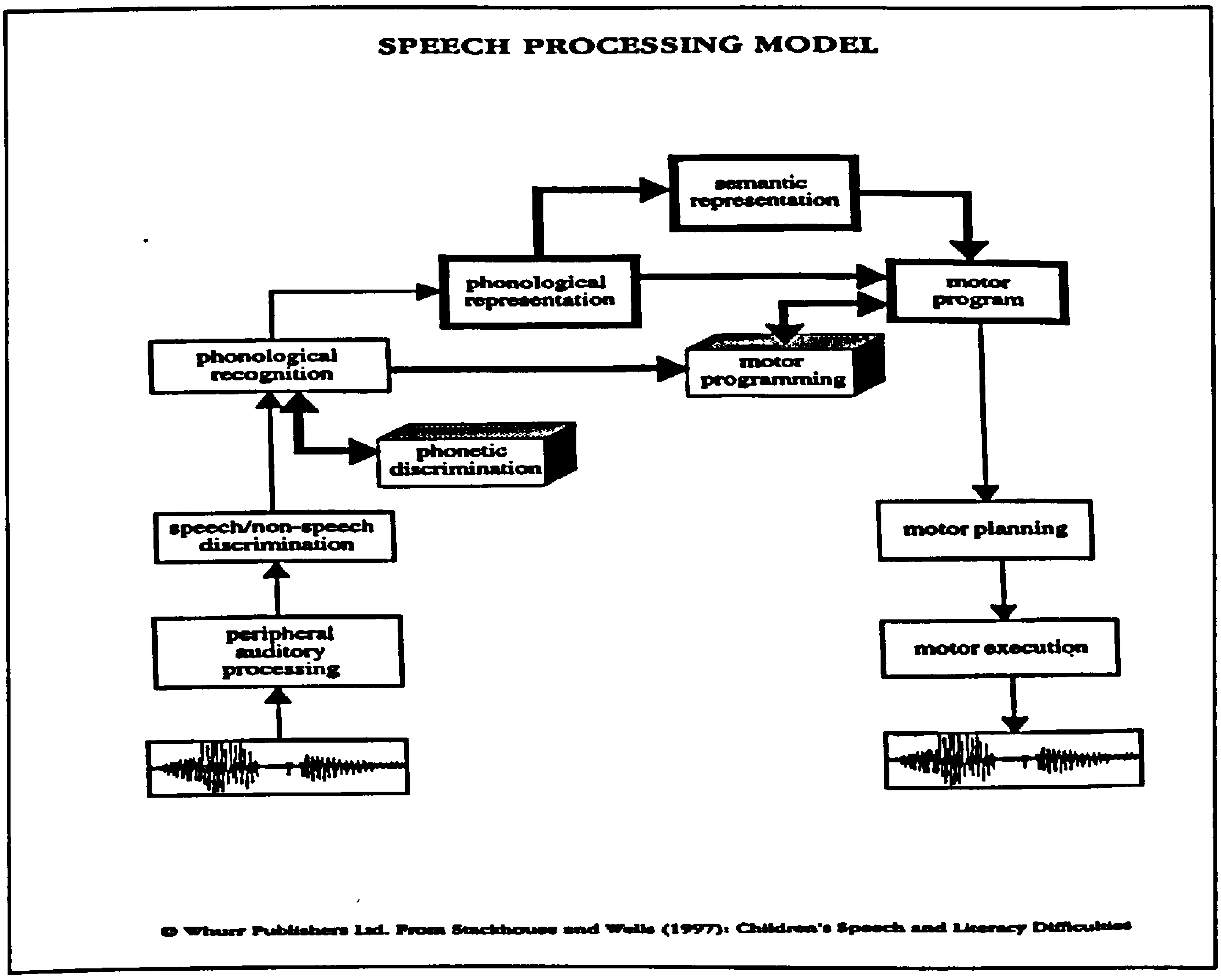

Figure 5.1 *A model of speech processing. (Stackhouse and Wells, 1997)*

While this model considers single word processing, and the experiment reported in the investigation was not designed in terms of such a model of speech processing, some interpretations can be made of the demands placed on each of the subjects in each of the three tasks. The most complex of these tasks requires the child to produce words spontaneously, whereby both phonological and semantic representations are required in order to select a target word (as in picture naming for example) and execute it using the motor programs required. In connected speech this type of processing would occur for a number of connected items - a more demanding task.

In imitating a single word however, there is no requirement for the same procedure to take place (though it may do so) because the child may store the word in short term memory, bypass the semantic and phonological representation components, and repeat it following the pathway from phonological recognition to motor execution. For a longer imitated utterance a similar pathway may be followed, assuming adequate short term memory skills.

However, it is also conceivable that in repeating an adult utterance, the child may change it in line with their own grammatical development (for example, changing "he's there" to "him there") thus accessing alternative levels where the imitation may not represent a straightforward attempt to produce an imitation of an adult phonological string. Thus the precise instructions given in an imitative task are important. The wording of this instruction may be devised to account for changes that are in line with grammatical development, in for example, "repeat exactly what I say".

In the DDK tasks, the same route as for an imitated utterance may be taken. That is, the children do not actually need to access their phonological representations in order to produce the sequences following the model given by the investigator. The assumption is then made that in producing a series of DDK syllables, the child does not have to access any higher levels of the model regarding the underlying phonological representations for the individual sounds. However, the error analyses of the DDK productions in the reported investigation indicate that it is not as straightforward as this. The "predictable" errors defined in the reported investigation may occur from the child drawing on his or her stored motor programmes for the target syllables. These stored motor programmes might be inadequate for a number of reasons. There may be inadequate phonological recognition leading to inadequate phonological representation, problems in mapping between adequate phonological representation and motor programmes or a problem with motor programming. Information from spontaneous and imitated single word production would help identify precisely where the difficulty lies.

"Non-predictable errors" may occur due to the demands of the maximum performance condition where the child is unable to plan and execute motor programmes accurately when there is the additional demand that this is done as fast as possible.

Thus understanding of the nature of phonological disability is problematical. If a child produces the DDK sequences using the same processes as in his or her single word and/or connected speech patterns (i.e. predictable error) only, then one may assume that the difficulty arises from the stored motor programmes for the target sound, regardless of the condition under which it is produced. Where non-predictable errors occur, this leads to the assumption that the difficulty does not simply stem from a phonological perspective per se, but rather a specific difficulty in producing an appropriate motor programme for producing the sounds in the maximum performance condition.

In the reported investigation, P1 and P14 produced their monosyllabic sequences either accurately or using non-predictable errors only, while the remaining P children produced them correctly, with predictable and with non-predictable errors. These remaining children appear therefore to be accessing a variety of levels of speech processing, indicating possible limitations with speech motor skill. In the bisyllabic sequences, only one P child however used predictable errors (P7), nine children produced either correct or non-predictable errors and the remaining four children (P2, P3, P4 and P6) produced the sequence accurately. In the polysyllabic sequences, two P children (P4 and P5) only produce predictable errors while the rest a mixture of accurate productions, predictable errors and non-predictable errors. It may be that Stackhouse and Well's (1998) assertion that DDK tasks tap only the most peripheral levels of speech output is an oversimplification. Using a variety of real words, non-words and DDK syllables produced in a variety of conditions (e.g. spontaneous, imitated, maximum performance) further understanding of a child's speech processing skills can be gained. There are implications for this in devising investigations for further research.

5.6 Critical review of the investigation and directions for future research

Many of the positive contributions to methodological issues from the reported investigation have been raised in the preceding sections. In considering directions for future research, there are some aspects of the investigation that require further discussion. A critical review of the investigation is presented below, followed by directions for future research.

5.6.1 Critical review of the reported investigation

5.6.1.1 *Subjects studied*

One of the points raised in chapters one and two regarding subject selection was the need to ensure that the two groups were differentiated only in terms of phonological skill. The standardised speech and language assessments carried out on each child were successful in distinguishing the two groups of children on the basis of their phonological ability, and this was confirmed using phonological process analysis of each child's single word and connected speech samples. All the children assigned to group P met the criteria defining them as phonologically disordered described by Grunwell (1981). However, it was pointed out that the P children as a group did have language skills (while still within an age appropriate range) that were lower than the N children as a group. Thus, it may be that while children diagnosed with a phonological disorder alone may be considered normal in other aspects of language development, these children may not be as proficient in their receptive and expressive language skills as children who have no speech output difficulties. An additional issue regarding the child subjects used in previous research concerned the desire to control for any effect therapeutic intervention may have on speech recorded in research. Unfortunately, it was not possible in the timescale of the reported investigation to recruit all the P children before they had been enrolled in a course of intervention. Inspection of the data gathered from the seven children who had already been enrolled in therapy revealed that the mean articulation rates for the imitated and spontaneous connected speech samples do not differ greatly from the group mean, or the mean for the seven children who had not been enrolled in therapy. Table 5.6 below shows the results of this analysis. An independent t-test comparing the mean values for these two sub-groups of disordered children shows that there is no significant difference between the rate values of those children who are already receiving therapy compared to those children who are not. Thus, where it can be construed that children currently enrolled in therapy may artificially reduce their connected speaking rates due to the expectations of the therapy situation (as suggested by Henry 1990), the children in the reported investigation did not seem to respond as though they perceived the recording sessions as similar to a therapy session. Either the recording session was not therefore perceived as a therapy session by these children, or children do not necessarily slow down their speaking rates in the presence of a speech and language therapist.

Variable	**Mean articulation rate for those children in therapy**	**Mean articulation rate for those children not in therapy**	**Mean articulation rate for the whole group of disordered children**
Imseg	7.56 seg/s	6.82 seg/s	7.19 seg/s
Imsyl	4.07 syll/s	3.72 syll/s	3.89 syll/s
Spseg	6.36 seg/s	6.10 seg/s	6.23 seg/s
Spsyl	3.39 syll/s	3.40 syll/s	3.39 syll/s

Table 5.6 Mean articulation rate values for the P children. The first column indicates the mean rate for the seven children who had been enrolled in therapy, the second column the mean rate for the seven children who had not yet been enrolled in therapy, and the third column the mean articulation rate for the whole group.

5.6.1.2 *Method used in the investigation*

In the results of the comparison of the articulation rate in the two groups of children, utterance length may have played a larger part and would require more control in any future investigation. Waters (1992) pointed out that the results of her investigation may be substantiated in a study using longer imitated and spontaneous utterances. With pre-school children however, it can be rather difficult to elicit such data, particularly with respect to their own particular mean length of utterance, where the data elicited in an imitated task should not contain stimuli that are beyond the bounds of the child's spoken language abilities. Gathering continuous data inevitably involves collecting data that crosses utterance boundaries, and it is of more value to determine rate from a continuous stream of speech as free of pauses as possible. By eliminating the pauses it is possible to gain a picture of the articulating time, though other constraints, such as linguistic and cognitive variables may play a greater role in the time taken to produce longer utterances (Campbell and Dollaghan, 1995).

The definition of an utterance in the reported investigation referred to one complete turn in the spontaneous connected speech data and one iteration of the experimental phrase "two naughty boys are picking" in the imitated connected speech data. It is possible that the natural slowing of a spontaneous utterance towards the final syllable may lead to a slower overall calculation of articulation rate in the spontaneous data in comparison to the imitated data. This is due to the fact that articulation rate was derived from one portion of the imitated carrier phrase through excluding the final words "some apples/bananas/oranges/flowers", while the spontaneous utterances contained a complete conversational turn. As pointed out in chapter three, section 3.3.1.2, if only an experimental portion of the spontaneous utterances were analysed, where the final word was disregarded for example, this would have depleted the pool of analysable data, with utterances that would have been shorter than the imitated utterances in terms of syllable length.

Furthermore, it is possible that in considering one conversational turn in the spontaneous connected data, an utterance may have contained more than one syntactic unit (and more than one communicated concept) while the imitated experimental phrase contained only one. Thus the effect of any concatenation of shorter spontaneous utterances into a single longer utterance was not considered.

These two observations may explain the longer utterance length found in the spontaneous than in the imitated utterances, thus direct comparison between the two connected speech contexts must be treated with caution.

It would also have been desirable to have used a modelled utterance that contained the potential for a greater range of systemic and structural simplification processes. Alternatively a series of imitated utterances could be devised. Thus, there would be sufficient data to probe any effects of increased articulation rate in the imitated context (if this was replicable) on the extent of 'forced errors' in comparison to the habitual rate of the children in their spontaneous connected speech. The instruction to repeat exactly what had been said would produce more valid data for analysis.

Analysis of the presence of forced errors and error patterns in the DDK tasks allowed for the identification of a tentative sub group of phonologically disordered children. With a wider range of data from imitated and DDK productions this sub group could have been explored in greater depth. The DDK repetitions collected do not represent an evaluation of the entire range of repetitive and alternating speech and oral movement abilities of the children. In future investigations of DDK productions this should be addressed more fully, where a representative sample of all possible places and manners of articulation, in non-word and real words can assist in the identification of the children who have speech motor difficulties. Additional tests of maximum performance such as lingual function (as in non-speech DDK tasks, such as moving the tongue from side to side) and maximum phonation times (as described by Thoonen et al (1999)) may provide additional evidence for detecting an underlying speech motor deficit in these children.

A number of factors must be taken into consideration in drawing conclusions based on the evidence presented in this thesis. In using statistical evidence to support any findings, it is crucial to point out that the two groups of children were both relatively small, with only fourteen children in each group providing the data for analysis, and the findings presented in the reported investigation may not necessarily reflect the full population sample.

Additionally, the analyses reported in the investigation relied heavily on the subjective perceptual judgement of the various productions produced by each of the children. As pointed out in chapter three, section 3.3.2.2, the preliminary perceptual judgements made following recording each child were supported using acoustic analysis techniques to assist in identifying the precise segments produced in each utterance or DDK sequence. This did, on the whole, provide a suitable, more objective protocol, with the exception of one particular child P3 where the difficulty of segmental identification was compounded by lax articulation. The decision to exclude this child from statistical analysis on this basis was therefore justified due to the difficulty encountered in making perceptual judgements of his data.

The findings in the reported investigation do suggest that the definition phonological disorder is still rather broad with the possibility that there are sub-groups of children within the phonologically disordered group. This notion is supported by the identification of a tentative sub group in the P children studied. A variety of different sub grouping systems are currently being used by clinicians and researchers alike, such as the classification system proposed by Dodd (1995). It isn't possible to classify the sub group of children identified in the current investigation according to Dodd's guidelines because of lack of repeated tokens of single word data. However, discussion with some of these children's therapists indicate that they do not all fit into the same categories of Dodd's system. Where P3 is described as producing consistent productions, he may fit Dodd's "consistent deviant" type, while P14 produces a number of inconsistent trials of the same target in a different manner, she may fit Dodd's "inconsistent deviant". Thus, the value of sub grouping P children can be questioned - not all children will fit into the classification systems proposed by any one author. Shriberg and Kwiatkowski's (1982) classification system described in chapter one is more suited to the description of individual children's presenting difficulties, with the findings of the current investigation supporting the notion that each level of potential deficit should be measured and interpreted in terms of the child's overall performance. This conclusion supports that of Thoonen et al where they suggest that "an alternative for the ......typological classification systems, a diagnostic system that is based on the recognition of the underlying deficit .....would be most useful for therapeutic purposes. Instead of determining which diagnostic category a particular child belongs, a more individualistic approach is advocated in which, for each particular speech disordered child, all relevant underlying factors are assessed." (1999:2)

Alternatively, the term developmental speech difficulty, or non-specific speech disorder as described by Thoonen et al (1999) may be more appropriate. This term may be used to define children who present in the clinic with abnormal or delayed speech patterns in the absence of known pathology. From such a term, the underlying deficits, whether they are cognitive, linguistic, sensory, environmental, social or motor in nature, may be assessed and intervention can be directed appropriately. Thus, the protocol used in the current investigation is proposed only as a supplementary diagnostic tool to help detect underlying speech motor deficits that can be used in the context of, for example, other available frameworks, such as the psycholinguistic framework of assessment proposed by Stackhouse and Wells (1997).

Some of the points raised in the preceding sections lend themselves towards the development of a protocol as described in section 5.4.2.2 above. Further research is required to address some of the outstanding methodological issues to enable such a protocol to have clinical use.

5.6.2 Directions for future research

The findings of the reported investigation go some way towards furthering understanding of the underlying speech motor skills in phonologically disordered and normally developing pre-school children, with suggestions for how to identify children with a speech motor constraint underlying their speech production difficulties. Further research is required in a number of areas both to confirm the findings presented and extend the knowledge base further.

In studying articulation rate in imitated connected speech the reported investigation used an utterance that was not able to probe all potential systemic and structural simplification processes that young N and P children may make. Further investigation of the articulation rate of pre-school children using a wider variety of imitated utterances is required to replicate and extend the finding that increased speed led to the production of forced errors when young children attempt to imitate an adult model.

There is further scope for investigating the phenomenon of increased rate = decreased accuracy in some children by comparing a larger age range of children, perhaps over a longer period of time in a longitudinal investigation of the development of articulation rate. Indeed, Smith, Kenney and Hussain (1996) advocate that longitudinal investigations of child speech provide greater insight into the developmental patterns that cannot be observed in studies of cross-sectional design. In carrying out such a longitudinal investigation of the normal development of DDK rate and DDK performance skills, the abilities of the P children in the reported investigation may reflect abilities seen in younger normally developing children.

Further investigation of DDK rates is required, particularly with regard the normative data reported in the literature. As pointed out in chapter two (section 2.2.1), there are discrepancies regarding DDK rate for same aged children on the same repetition sequence (for example where the mean DDK rate for [pʌ] in the 5;00 - 5;06 age range reported by Robbins and Klee (1987) is 4.76 repetitions/s, whilst St Louis and Ruscello (1987) report a rate of 3.47 repetitions/s for the same age range.) This disparity clearly indicates a need for the DDK rate norms to be re-evaluated. The methodological points raised throughout this thesis indicate that a more robust procedure for the collection and analysis of DDK rate is required in undertaking further research. A future investigation may apply the procedures designed in the reported investigation to re-evaluate the norms, perhaps as an additional feature of any longitudinal research into development of articulation rate and DDK rate in normally developing children.

Further information could be gathered using different DDK stimuli, for example real words, nonsense word forms and non-speech DDK tasks in addition to alternating tests of maximum performance. The effect of asking children to produce real words at as fast a rate as possible, in addition perhaps to imitated connected speech as fast as possible opens up the possibilities of investigating the occurrence of errors in relation to increased rates of production. This would further the knowledge on any underlying speech motor constraints that affect speech output, and provide more information on children's speech processing skills.

The use of the error analysis has unequivocally been shown to be of value in identifying P children who may have difficulties with speech motor skills. The next stage would be to extend this type of analysis with a greater range of imitated and DDK stimuli, and to follow the progress through therapy of those children who may potentially be identified as having poorer speech motor skills. Steps towards using the protocol described for the collection, analysis and interpretation of rate data in young children as a tool for the differential diagnosis of an underlying speech motor deficit in children with a developmental speech difficulty require to be taken.

5.7 Summary and Conclusions

The title of the thesis, "Measuring speech motor skills in phonologically disordered pre-school children and their normally developing peers", incorporates a number of different issues that have been addressed in the thesis. The speech motor skills of phonologically disordered pre-school children were measured using a number of techniques previously reported in the literature as indicative of this ability.

The main findings of the thesis and the conclusions drawn from them are summarised below.

- Phonologically disordered children, as a group, have significantly slower articulation rates in both seg/s and syll/s than their normally developing peers in both imitated and spontaneous connected speech samples. The range of mean values within each group overlap, where some of the P children have mean articulation rates that are comparable to some of the N children. While the group finding is indicative of poorer speech motor skills in the P children studied in the investigation, it indicates that not all of these children necessarily have poorer speech motor skills.

- A measure of articulation rate in seg/s reveals more interesting data in young normally developing and phonologically disordered children, where children in either category, though more so in the latter group, will have structural simplifications in their connected speech. In the reported investigation P children tended to produce fewer segments/syllable than N children. The statistical significance of the difference between the articulation rates of the two groups of children when measured in seg/s is higher than in syll/s advocating its use as a more robust measure of articulation rate.
- In the reported investigation, for both groups of children, the imitated connected speech was produced at a faster articulation rate than the spontaneous connected speech. This led to a number of forced errors, defined as a forced error that was present only in the imitated connected speech data and not in either the single word or spontaneous connected speech data taken from the same child. A greater proportion of P children made forced errors in their imitated connected speech than N children. This finding indicated that in increasing the tempo with which the children produced the imitated utterances they tended to forgo accuracy. This was interpreted as indicative of immature speech motor skills in these children.
- No significant difference was found between the two groups of children in their DDK rates. There was one exception to this finding, where the P children had significantly slower DDK rate for accurate productions of the monosyllable /kə/ than the N children. However, far fewer P children were able to produce the DDK syllables accurately than N children and the error patterns produced by each child yielded interesting data for further analysis and interpretation.
- The error patterns produced in the DDK sequences were analysed in terms of the children's speech production skills in their single word and connected speech samples. The children either produced the syllable accurately, made an error that was predictable on the basis of their single word and connected speech abilities or made an error that was not predictable on the basis of their single word and connected speech abilities. The P children as a group made a far greater proportion of non-predictable errors than the N children who made fewer errors overall. Furthermore, the P children were unable to sequence two or three places of articulation as successfully as the N children.
- Analysis of the P children's forced errors in the imitated utterances and non-predictable errors in the DDK tasks led to the identification of a sub group of children identified as

having an underlying speech motor deficit. The criteria for inclusion in this sub group was presence of each of the following: forced error in imitated utterances, non-predictable DDK productions and difficulty alternating places of articulation in the DDK task.

- The findings of the reported investigation have shown that there is a sub-group of phonologically disordered children who present with an underlying speech motor skills deficit. The issue of sub grouping children is however contentious, with some children fitting the profiles described by some authors while others do not. Of more importance therefore is the ability to identify the underlying deficits contributing to the manifestation of a developmental speech difficulty. These may fall into any of the categories cognitive, linguistic, sensory, emotional, social or motor. The findings of the reported investigation have been interpreted in relation to the assessment of underlying speech motor skills of such children, and the development of a suitable protocol is proposed.
- Five of the P children in the investigation were described as having an underlying speech motor deficit on the basis of the criteria described above. Additional anecdotal evidence supports this finding, where three of the five P children in the investigation who were identified as having an underlying speech motor deficit failed to progress with cognitive / linguistic approaches to therapy (one left the area so follow up evaluation wasn't possible). Of the children who were not identified as having this type of underlying deficit, two children have been discharged following a cognitive / linguistic approach to therapy, four are making progress in therapy with indications of underlying linguistic difficulties and no indications of speech motor constraints, and for the remaining three the information is not available.
- Finally, the thesis presented proposes the development of an appropriate methodology for the collection, analysis and interpretation of articulation rate, DDK rate, and forced error productions in young children. There is a requirement that the normative data used as a clinical and research guideline needs to be completely overhauled. The deficiencies highlighted in the various published protocols require addressing in order to provide valid and reliable normative data.

Appendix 1
Information letter, consent form and short questionnaire for group N children

Queen Margaret College
EDINBURGH

Dear Parent,

Motor Speech Skills Research Project

I am a registered Speech and Language Therapist working as a research student at Queen Margaret College. I am conducting a study into the speech motor skills of young children. In order to carry out this work, I hope to record samples of speech from a number of children, who are aged between 3 years 10 months and 4 years 10 months.

The staff at your child's playgroup have kindly agreed to assist in this study by handing out these letters.

I hope to visit you and your child at home to explain a little more about the project and collect some information about your child's speech and language skills. A random selection of children will be invited to the Department of Speech and Language Science at Queen Margaret College where each child will be tape-recorded saying a number of things. This recording will include repeating simple sentences, listening to and re-telling a story and repeating various speech sounds as quickly as possible.

The recorded speech will provide information regarding the kinds of skills involved in learning to speak. This information will be of use to speech and language therapists in the treatment of speech disorders.

If you would be willing for your child to participate in this study, could you please complete the attached consent form, short questionnaire and return it to me in the reply paid envelope provided.

If you have any questions you would like to discuss concerning the project, both myself and my supervisors would be happy to speak to you at the above telephone number during office hours.

Yours sincerely

Wendy M M Cohen
BSc(Hons) RegMRCSLT
Research Student

Supervisors :-

Daphne Waters PhD BSc RegMRCSLT
Nigel Hewlett BA MA PhD PGCE
Professor W J Hardcastle BA MA DipPhon PhD

Queen Margaret College
EDINBURGH

Motor Speech Skills Research Project
Consent Form

- I agree to allow my child to take part in the above study.
- I have understood the information I have been given about the project and the methods which will be used to carry out the project.
- I have had an opportunity to ask any questions about my child's participation in this study.
- I understand that my child is under no obligation to take part in this study and I am under no obligation to give my permission for him/her to do so.
- I understand that any audio or written records will only be used for research and / or teaching purposes and that my child will not be identified by name.
- I understand that my child and I have the right to withdraw from this study at any time for any reason.
- I understand that both my child's and my own right to confidentiality will be respected at all times.

Name of child : ________________________________

Signature of parent/guardian : ________________________________

Name of parent/guardian: ________________________________

Date : ________________________________

Queen Margaret College
EDINBURGH

Motor Speech Skills Research Project
Parent Questionnaire

I am asking for a small amount of voluntary information about the children participating in the above study. All information will remain strictly confidential.

1. Child's date of birth ....

2. Place in family (e.g. 1st of 2 children)...

3. Do you, or any other person in close contact with your child, use a language other than English ? If YES please specify.
   ....
   ....

4. Has your child been referred to a speech and language therapist for any reason?
   ....
   ....

5. Has she / he attended a course of speech and language therapy? If YES please give as many details as you can.
   ....
   ....

6. Have you ever been concerned that you child is not hearing properly?
   ....
   ....

7. Has your child ever suffered from sore ears (ear infections) ? If YES, please say when and how often.
   ....
   ....

Thank you very much for your help.

Appendix 2
Information letter, consent form and short questionnaire for group P children

Queen Margaret College
EDINBURGH

Dear Parent,

Motor Speech Skills Research Project

I am a registered Speech and Language Therapist working as a research student at Queen Margaret College. I am conducting a study into the speech motor skills of young children. In order to carry out this work, I hope to record samples of speech from a number of children who are having difficulty with their speech sounds, who are aged between 3 years 10 months and 4 years 10 months.

Your speech and language therapist has suggested to me that your child may be a suitable candidate for the project.

I hope to visit you and your child at home to carry out some speech and language assessments and to explain a little more about the project. I may then invite you and your child to the Department of Speech and Language Science at Queen Margaret College in order to tape record your child saying a number of things. This recording will include asking your child to repeat simple sentences, listen to and re-tell a story, and repeat various speech sounds as quickly as possible.

The recorded speech will provide information regarding the kinds of difficulties your child is having. This information will be of use to speech and language therapists in the treatment of speech disorders.

If you would be willing for your child to participate in this study, could you please complete the attached consent form, short questionnaire and return it to me in the reply paid envelope provided.

If you have any questions you would like to discuss concerning the project, both myself and my supervisors would be happy to speak to you at the above telephone number during office hours.

Yours sincerely

Wendy M M Cohen
BSc(Hons) RegMRCSLT
Research Student

<u>Supervisors :-</u>

Daphne Waters PhD BSc RegMRCSLT
Nigel Hewlett BA MA PhD PGCE
Professor W J Hardcastle BA MA DipPhon PhD

Queen Margaret College

EDINBURGH

Motor Speech Skills Research Project
Consent Form

- I agree to allow my child to take part in the above study.
- I have understood the information I have been given about the project and the methods which will be used to carry out the project.
- I have had an opportunity to ask any questions about my child's participation in this study.
- I understand that my child is under no obligation to take part in this study and I am under no obligation to give my permission for him/her to do so.
- I understand that any audio or written records will only be used for research and / or teaching purposes and that my child will not be identified by name.
- I understand that my child and I have the right to withdraw from this study at any time for any reason, without prejudice to future treatment.
- I understand that both my child's and my own right to confidentiality will be respected at all times.
- I agree / do not agree to my child's GP being informed about his/her participation in this study * Name of G.P. : ______________________

* **N.B. This information is not mandatory**

Name of child : ______________________________

Signature of parent/guardian : ______________________________

Name of parent/guardian: ______________________________

Date : ______________________________

Queen Margaret College
EDINBURGH

Motor Speech Skills Research Project
Parent Questionnaire

I am asking for a small amount of voluntary information about the children participating in the above study. All information will remain strictly confidential.

1. Child's date of birth ....

2. Place in family (e.g. 1st of 2 children)...

3. Do you, or any other person in close contact with your child, use a language other than English ? If YES please specify.
....
....

4. Has your child been referred to a speech and language therapist for any reason?
....
....

5. Has she / he attended a course of speech and language therapy? If YES please give as many details as you can.
....
....

6. Have you ever been concerned that you child is not hearing properly?
....
....

7. Has your child ever suffered from sore ears (ear infections) ? If YES, please say when and how often.
....
....

Thank you very much for your help.

Appendix 3
Consonant inventories per subject

Individual consonant inventories for each child are shown in figures A.1 - A.6 below, detailing the presence of each consonant from the available single word and connected speech data. The presence of each consonant is shown by shading.

Notes : Figure A.1 shows the inventories for subjects N1, N2, N3, N4 and N5
Figure A.2 shows the inventories for subjects N6, N7, N8, N9, N10 and N11
Figure A.3 shows the inventories for subjects N12, N13, N14, P1, P2 and P3
Figure A.4 shows the inventories for subjects P4, P5, P6, P7, P8 and P9
Figure A.5 shows the inventories for subjects P10, P11, P12, P13 and P14

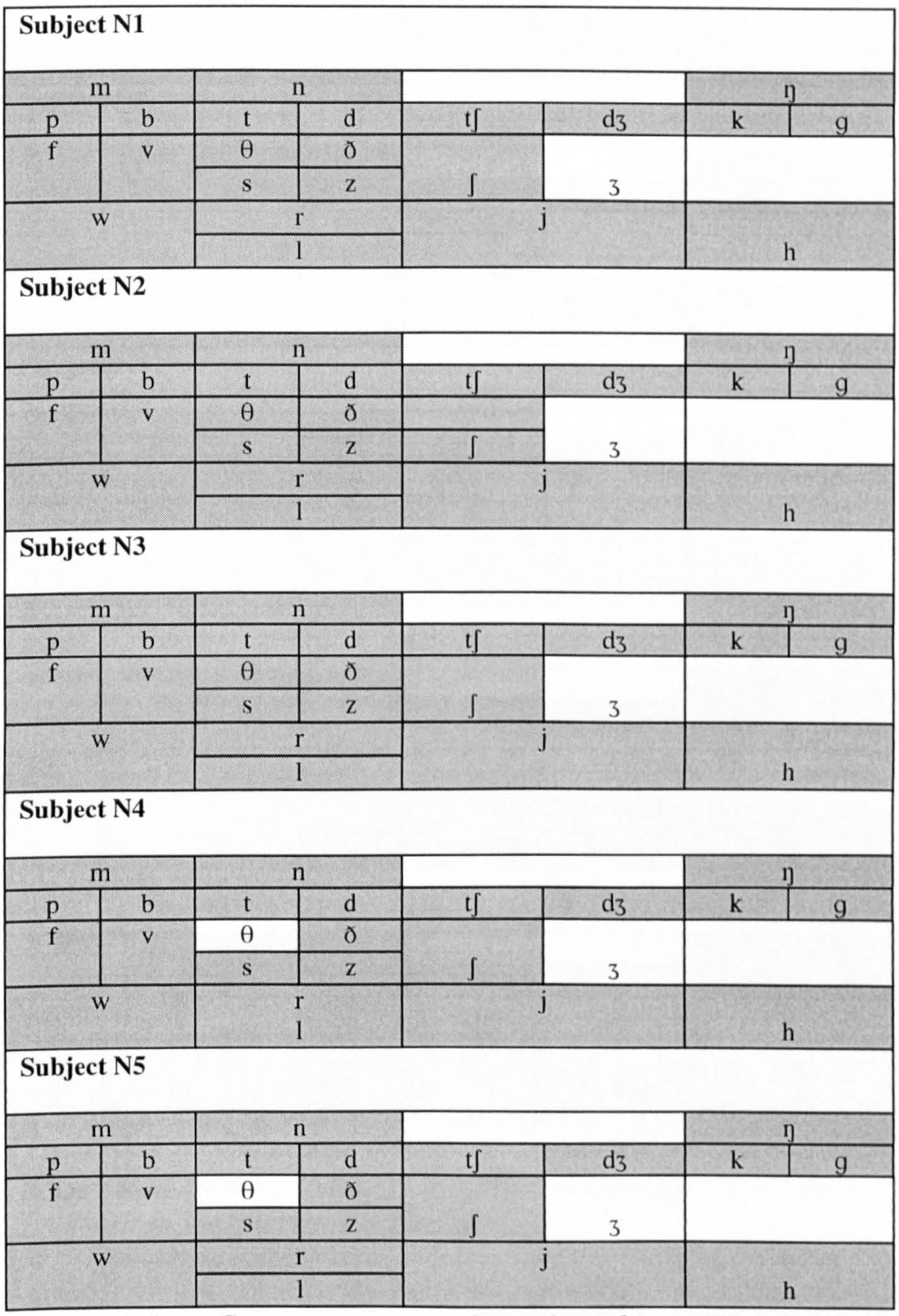

Figure A.1 Consonant system charts for subjects N1, N2, N3, N4 and N5. The presence of shading indicates that the consonant is used either syllable initially, syllable finally or in the intervocalic position.

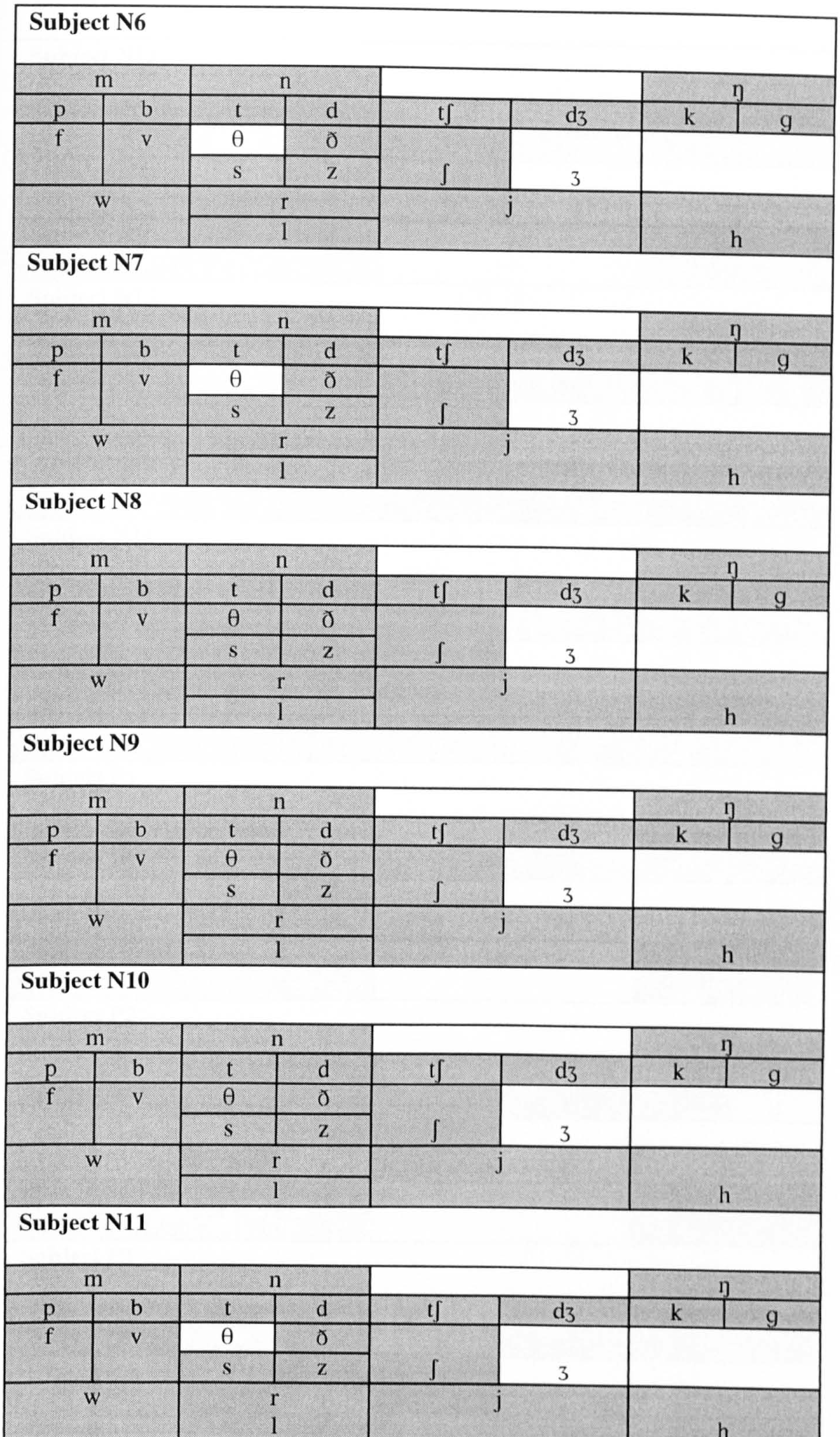

Figure A.2 *Consonant system charts for subjects N6, N7, N8, N9, N10 and N11. The presence of shading indicates that the consonant is used either syllable initially, syllable finally or in the intervocalic position.*

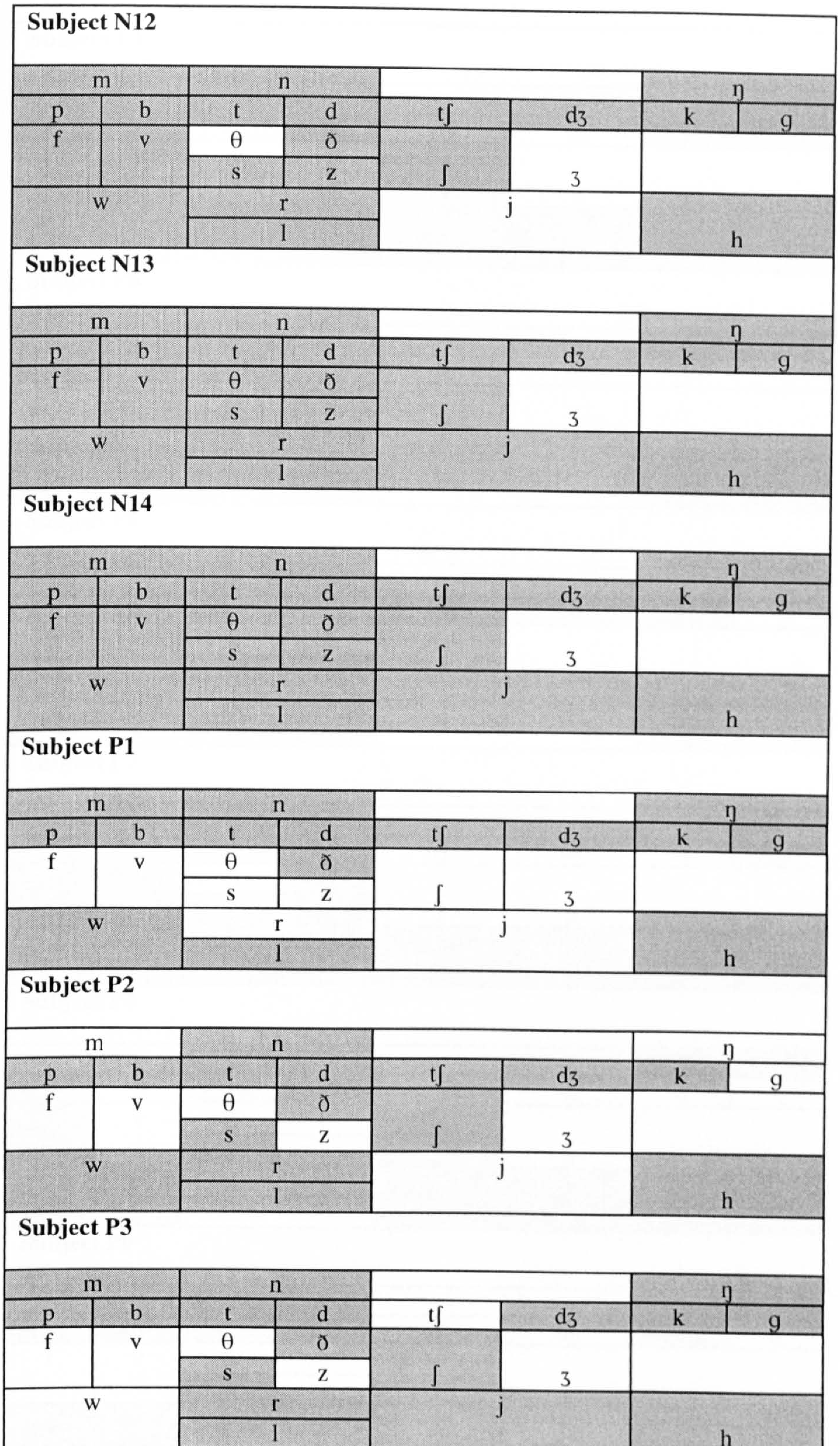

Figure A.3 *Consonant system charts for subjects N12, N13, N14, P1, P2 and P3. The presence of shading indicates that the consonant is used either syllable initially, syllable finally or in the intervocalic position.*

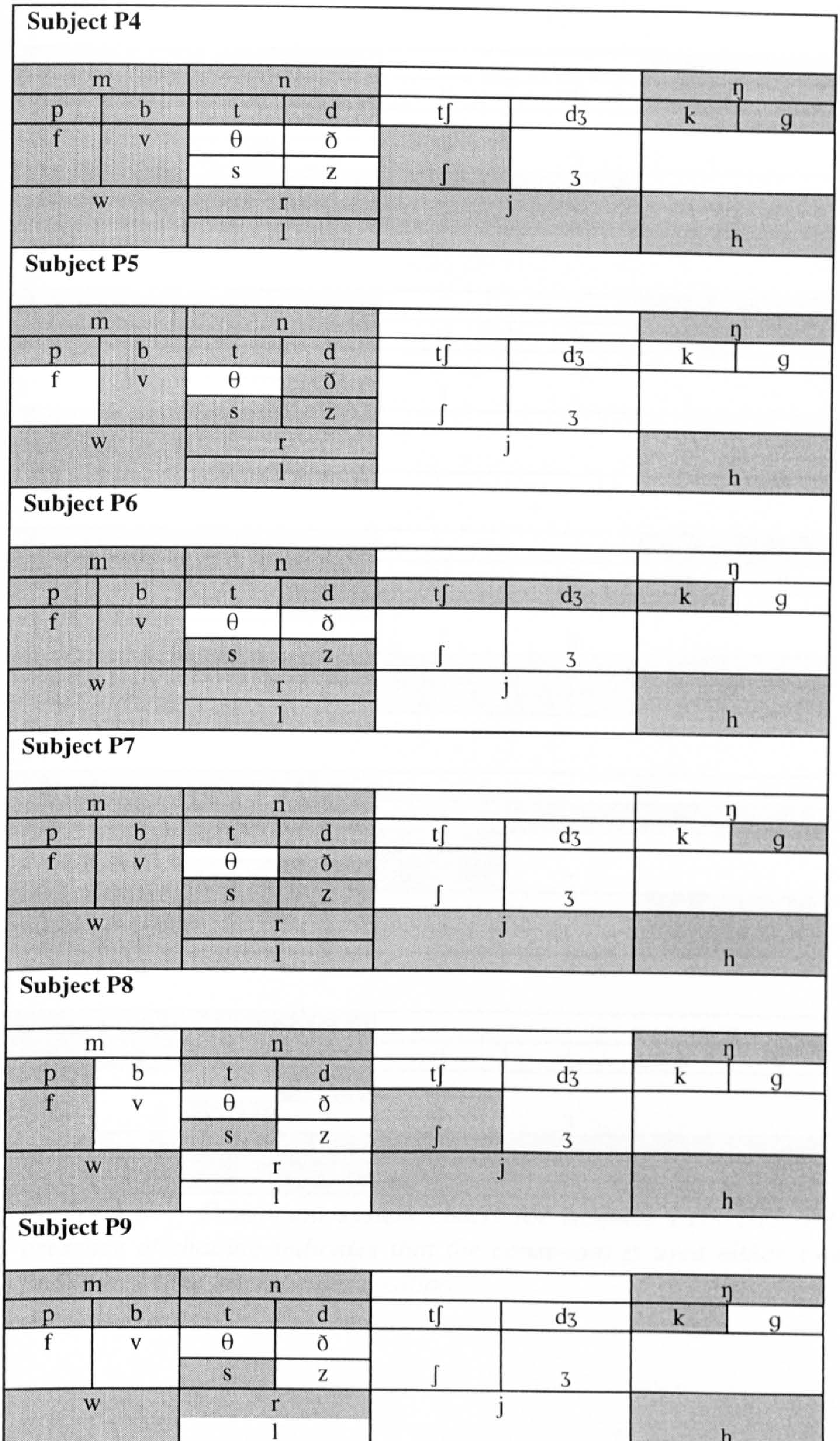

Figure A.4 *Consonant system charts for subjects P4, P5, P6, P7, P8 and P9. The presence of shading indicates that the consonant is used either syllable initially, syllable finally or in the intervocalic position.*

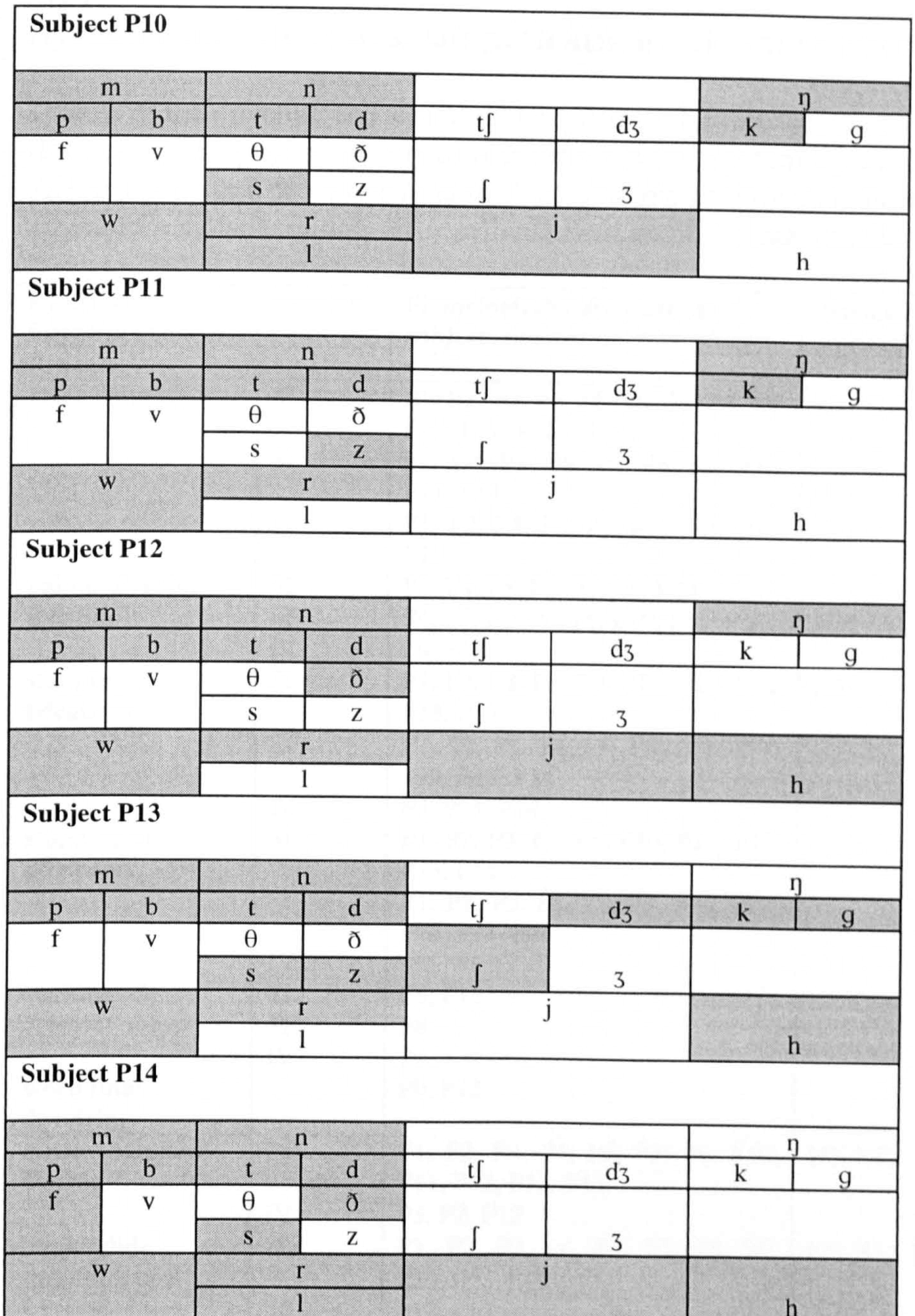

Figure A.5 Consonant system charts for subjects P10, P11, P12, P13 and P14. The presence of shading indicates that the consonant is used either syllable initially, syllable finally or in the intervocalic position.

Appendix 4
Systemic and structural simplifications evident in the data

Details of the systemic and structural simplification processes used by each of the normally developing and phonologically disordered children. Systemic processes are shown in table A.1 and structural processes in table A.2. Syllable position is indicated where applicable, where SI = syllable initial, SF = syllable final and IV = intervocalic.

Systemic Simplification Process	position	Phonologically disordered subjects presenting with process	Normally developing subjects presenting with process
velar fronting	SI	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14	
	SF	P2, P4, P5, P6, P7, P8, P9, P10, P11, P14	
	IV	P1, P2, P5, P6, P7, P8, P11, P12, P14	
palato-alveolar fronting	SI	P3, P4, P5, P6, P7, P8, P13	
	SF	P4, P5, P6, P7, P8, P10, P11, P13	N12
	IV	P9, P13	
stopping of fricatives	SI	P1, P2, P3, P8, P9, P10, P11, P12, P13, P14	N4
	SF	P1, P2, P3, P4, P8, P9, P10, P11, P12, P13, P14	N7
	IV	P4, P11, P14	
stopping of affricates	SI	P1, P2, P3, P8, P9, P10, P11, P12, P13, P14	
	SF	P1, P2, P3, P4, P8, P9, P10, P11, P12, P13, P14	
	IV		
backing of alveolar stops	SI	P8, P13	
	SF	P8	
	IV	P1	
word final devoicing		P9, P12	
context sensitive voicing	Pre vocalic	P1, P2, P3, P4, P5, P7, P9, P10, P11, P12, P13, P14	N3, N12
	IV	P3, P7, P12	
liquid/glide simplification	SI	P1, P2, P3, P4, P6, P7, P8, P9, P10, P13, P14	N5, N12, N14
	SF	P12, P14	
	IV	P7, P8, P12, P13	N4
/θ/ ->/f/	SI	P4, P5, P6, P7, P14	N4, N5, N6, N8, N9, N11, N12, N14
	SF	P2, P4, P6, P7, P13, P14	N3, N4, N5, N6, N8, N9, N10, N11, N12, N13, N14
	IV		N4, N12

Table A.1 Table showing those N and P children using each of the systemic simplification processes, by syllable place where applicable

Structural Simplification Process	**position**	**Phonologically disordered subjects presenting with process**	**Normally developing subjects presenting with process**
initial consonant deletion	SI	P4, P9, P11, P12, P13	
final consonant deletion	SF	P1, P2, P4, P8, P10, P11, P12, P14	
initial cluster reduction	SI	P1, P2, P3, P4, P5, P7, P8, P9, P10, P11, P12, P13, P14	N4, N5, N6, N7, N12
final cluster reduction	SF	P1, P3, P4, P8, P9, P10, P11, P12, P13, P14	

Table A.2 Table showing those N and P children using each of the structural simplification processes, by syllable place where applicable

Appendix 5
Phonological processes by speech context per subject

Notes : Where the process is present this is denoted by "yes",
Where the process is not present this is denoted by "no"
Where there is no information from the data to indicate whether or not the process is present this is denoted by "don't know"

N1			
Simplification process	**In single word data?**	**In imitated speech?**[3]	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no
N2			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

[3] In the experimental portion of the imitated phrase

N3			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	yes
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N4			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	yes	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	no
final cluster reduction	no	don't know	no

N5			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	yes	don't know	no
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	no
final cluster reduction	no	don't know	no

N6			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	no
final cluster reduction	no	don't know	no

N7			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	yes
stopping of fricatives	no	yes	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	no
final cluster reduction	no	don't know	no

N8			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N9			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	yes

N10			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N11			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N12			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	yes	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	yes	no
liquid/glide simplification	yes	no	no
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N13			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

N14			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	no	no	no
palato-alveolar fronting	no	don't know	no
stopping of fricatives	no	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	yes	don't know	yes
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

P1			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	no	yes
palato-alveolar fronting	yes	don't know	don't know
stopping of fricatives	yes	no	yes
stopping of affricates	no	don't know	no
backing of alveolar stops	no	yes	no
word final devoicing	no	no	no
context sensitive voicing	yes	no	yes
liquid/glide simplification	yes	no	no
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P2			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	yes	yes
palato-alveolar fronting	no	don't know	no
stopping of fricatives	yes	no	no
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	yes	no
liquid/glide simplification	yes	no	yes
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	no
final cluster reduction	no	don't know	yes

P3			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	no	no
palato-alveolar fronting	yes	don't know	no
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	yes	yes	yes
liquid/glide simplification	yes	yes	yes
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	yes	no
initial cluster reduction	yes	don't know	no
final cluster reduction	yes	don't know	yes

P4

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	no	yes
palato-alveolar fronting	yes	don't know	no
stopping of fricatives	yes	no	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	yes	no	yes
liquid/glide simplification	yes	yes	yes
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	yes
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P5

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	yes	yes
palato-alveolar fronting	yes	don't know	no
stopping of fricatives	no	no	yes
stopping of affricates	no	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	no	yes	no
context sensitive voicing	no	no	yes
liquid/glide simplification	no	no	no
[θ] - [f]	yes	don't know	don't know
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	yes
final cluster reduction	no	don't know	no

P6

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	no	yes
palato-alveolar fronting	yes	don't know	yes
stopping of fricatives	no	no	no
stopping of affricates	yes	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	no	no
liquid/glide simplification	yes	don't know	no
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	no	don't know	no
final cluster reduction	no	don't know	no

P7

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	yes	yes
palato-alveolar fronting	yes	don't know	yes
stopping of fricatives	no	yes	yes
stopping of affricates	no	don't know	no
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	yes	yes	yes
liquid/glide simplification	yes	yes	yes
[θ] - [f]	yes	don't know	yes
initial consonant deletion	no	no	no
final consonant deletion	no	no	no
initial cluster reduction	yes	don't know	yes
final cluster reduction	no	don't know	no

P8

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	no	yes
palato-alveolar fronting	yes	don't know	don't know
stopping of fricatives	yes	yes	don't know
stopping of affricates	yes	don't know	don't know
backing of alveolar stops	no	yes	yes
word final devoicing	no	no	no
context sensitive voicing	no	yes	yes
liquid/glide simplification	yes	don't know	yes
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	no	yes
initial cluster reduction	yes	don't know	don't know
final cluster reduction	yes	don't know	don't know

P9

Simplification process	In single word data?	In imitated speech?	In spontaneous speech?
velar fronting	yes	no	yes
palato-alveolar fronting	no	don't know	no
stopping of fricatives	yes	don't know	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	no	no
word final devoicing	yes	don't know	yes
context sensitive voicing	yes	yes	no
liquid/glide simplification	yes	don't know	yes
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P10			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	yes	yes
palato-alveolar fronting	yes	don't know	don't know
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	don't know
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	yes	yes	no
liquid/glide simplification	yes	no	yes
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	don't know
final cluster reduction	yes	don't know	don't know

P11			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	yes	yes
palato-alveolar fronting	yes	don't know	don't know
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	no	no
word final devoicing	no	no	no
context sensitive voicing	yes	yes	no
liquid/glide simplification	no	yes	no
[θ] - [f]	no	don't know	no
initial consonant deletion	yes	no	yes
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P12			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	yes	yes
palato-alveolar fronting	no	don't know	no
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	yes	no	yes
context sensitive voicing	yes	yes	no
liquid/glide simplification	no	no	yes
[θ] - [f]	no	don't know	no
initial consonant deletion	no	no	yes
final consonant deletion	yes	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P13			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	yes	yes
palato-alveolar fronting	yes	don't know	no
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	yes	yes	yes
liquid/glide simplification	yes	yes	yes
[θ] - [f]	yes	don't know	no
initial consonant deletion	yes	yes	yes
final consonant deletion	yes	yes	no
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	don't know	yes

P14			
Simplification process	**In single word data?**	**In imitated speech?**	**In spontaneous speech?**
velar fronting	yes	don't know	yes
palato-alveolar fronting	no	don't know	no
stopping of fricatives	yes	yes	yes
stopping of affricates	yes	don't know	yes
backing of alveolar stops	no	don't know	no
word final devoicing	no	no	no
context sensitive voicing	no	yes	no
liquid/glide simplification	yes	don't know	yes
[θ] - [f]	yes	don't know	no
initial consonant deletion	no	no	no
final consonant deletion	no	yes	yes
initial cluster reduction	yes	don't know	yes
final cluster reduction	yes	yes	no

Appendix 6
Transcribed single word utterances per subject

Broad phonetic transcription of the single word utterances from the Metaphon Screening Test for all the normally developing and phonologically disordered children in the investigation

Adult target-orthographic	Adult target - phonetic	N1	N2	N3	N4	N5	N6	N7
cup	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp
gun	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn
knife	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf
sharp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp
fish	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ
kiss	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs
sock	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk
glass	glas	glas	glas	glas	glas	gas	las	glas
watch	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ
nose	noz	noz	noz	noz	noz	nos	noz	noz
mouth	mʌʉθ	mʌʉθ	mʌʉθ	mʌʉf	mʌʉf	mʌʉθ	mʌʉs	mʌʉθ
yawn	jɔn	jɔn	jɔn	jɔn	jɔn	jɔn	jɔn	jɔn
leaf	lif	lif	lif	lif	lif	liv	lif	lif
thumb	θʌm	θʌm	θʌm	θʌm	fʌm	fʌm	fʌm	θʌm
foot	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt
toe	to	to	to	to	to	to	to	to
snake	snek	snek	snek	snek	snek	snek	snek	snek
van	van	van	van	van	ban	van	van	van
fast	fast	fast	fast	fast	fast	fast	fast	fast
girl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl
stairs	sterz	sterz	sterz	sterz	sterz	sterz	sterz	sterz
big	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg
jam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam
house	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉs
path	paθ	paθ	paθ	paf	paf	paf	pas	paθ
door	dor	dor	dor	dor	dor	dor	dor	dor
smoke	smok	smok	smok	smok	smok	smok	smok	smok
bridge	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ
train	tren	tren	tren	tren	twen	ten	tren	ten
chair	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer
red	rɛd	rɛd	rɛd	rɛd	rɛd	rɛd	rɛd	rɛd
spoon	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn
plane	plen	plen	plen	plen	plen	pen	plen	plen
fly	flae	flae	flae	flae	flae	-	flae	flae
sky	skae	skae	skae	skae	skae	skae	skae	skae
sun	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn
wing	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪnz	wɪŋ	wɪŋ
splash	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ
tent	tɛnt	tɛnt	tɛnt	tɛnt	tɛnt	-	tɛnt	tɛnt
salt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt
crab	krab	krab	krab	krab	krab	krab	krab	krab
sweet	swit	swit	swit	swit	swit	swit	swit	swit
sleeve	sliv	sliv	sliv	sliv	sliv	sliv	sliv	sliv
zip	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp

Adult target-orthographic	Adult target - phonetic	N8	N9	N10	N11	N12	N13	N14
cup	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp	kʌp
gun	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn	gʌn
knife	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf	nʌɪf
sharp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp	ʃarp
fish	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ	fɪʃ
kiss	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs	kɪs
sock	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk	sɔk
glass	glas	glas	glas	glas	glas	glas	glas	gɪras
watch	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔtʃ	wɔts	wɔtʃ	wɔtʃ
nose	noz	noz	noz	noz	noz	noz	noz	noz
mouth	mʌʉθ	mʌʉf	mʌʉθ	mʌʉθ	mʌʉf	mʌʉf	mʌʉf	mʌʉf
yawn	jɔn	jɔn	jɔn	jɔn	jɔn	ðɔn	jɔn	jɔn
leaf	lif	lif	lif	liv	lif	lif	liv	liv
thumb	θʌm	fʌm	fʌm	θʌm	fʌm	fʌm	θʌm	fʌm
foot	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt	fʉt
toe	to	to	to	to	to	to	to	to
snake	snek	snek	snek	snek	snek	snek	snek	snek
van	van	van	van	van	van	van	van	van
fast	fast	fast	fast	fast	fast	fast	fast	fast
girl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl	gɪrl
stairs	sterz	sterz	sterz	sterz	sterz	sterz	sterz	sterz
big	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg	bɪg
jam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam	dʒam
house	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉs	hʌʉ	hʌʉs	hʌʉs
path	paθ	paf	paf	paf	paf	-	paθ	paf
door	dor	dor	dor	dor	dor	dor	dor	dor
smoke	smok	smok	smok	smok	smok	smok	smok	smok
bridge	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	brɪdʒ	bɪdʒ	brɪdʒ	brɪdʒ
train	tren	tren	tren	tren	tren	tsen	tren	tren
chair	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer	tʃer
red	rɛd	rɛd	rɛd	rɛd	rɛd	rɛd	rɛd	ʋɛd
spoon	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn	spʉn
plane	plen	plen	plen	plen	plen	plen	plen	pwen
fly	flae	flae	flae	flae	flae	flae	flae	flae
sky	skae	skae	skae	skae	skae	skae	skae	skae
sun	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn	sʌn
wing	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪŋ	wɪŋ
splash	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ	splaʃ
tent	tɛnt	tɛnt	tɛnt	tɛnt	tɛnt	tɛnt	tɛnt	tɛnt
salt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt	sɔlt
crab	krab	krab	krab	grab	krab	krab	krab	krab
sweet	swit	swit	swit	swit	swit	swit	swit	swit
sleeve	sliv	sliv	sliv	sliv	sliv	sliv	sliv	sliv
zip	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp	zɪp

Adult target-orthographic	Adult target - phonetic	P1	P2	P3	P4	P5	P6	P7
cup	kʌp	tʌp	mʌdi	kʌp	tʌp	tʌp	tʌp	dʌp
gun	gʌn	dʌn	dʌn	gʌn	dʌn	dʌn	dʌn	dʌn
knife	nʌɪf	nʌɪt	nʌɪd	nʌɪf	nʌɪp	nʌɪs	mʌɪf	nʌɪf
sharp	ʃarp	dʒarp	ʃap	ta:p	sarp	swarp	sarp	sarp
fish	fɪʃ	dʒɪt	dɪʃ	dɪst	fɪθ	sɪs	fɪs	fɪs
kiss	kɪs	kɪh	kɪs	kɪt	tɪθ	tɪsɪŋ	tɪs	dɪs
sock	sɔk	dɔk	çɔʔ	tɔk	sɔʔ	sɔt	sɔk	sɔts
glass	glas	dak	jas	glad	das	glas	dras	dras
watch	wɔtʃ	wɔtʃ	wɔtʃ	wɔt	wɪts	wɔtʃ	wɔts	wɔts
nose	noz	nod	nod	nod	noɪz	noz	moz	noɪz
mouth	mʌʉθ	mʌʉt	mʌʉf	mʌʉf	mʌʉf	tis	mʌʉf	mʌʉf
yawn	jɔn	hɔn	jɔ:n	jɔn	dɔn	jɔn	ɔn	jɔn
leaf	lif	lit	li:h	liv	rit	liz	liv	lif
thumb	θʌm	dʌm	-	dʌm	fʌm	sʌm	fʌm	fʌm
foot	fʉt	dʉt	-	dʉʔ	fʉʔ	sʉt	fʉt	fʉti
toe	to	do	to:	tod	toz	to	toz	toi
snake	snek	nek	çnet	nek	sek	sɪnet	snek	sedɪ
van	van	van	han	van	van	van	van	vani
fast	fast	dat	hast	dat	fas:	sast	fast	fa:st
girl	gɪrl	dɪrəl	dɪl	gɪrl	dɪrəl	dɪrəl	dɪrəl	dɪrəl
stairs	sterz	ter	sterz	terd	sterz	sterz	sterz	serz
big	bɪg	bɪg	bɪd	bɪg	blɪd	bɪd	bɪg	bɪg
jam	dʒam	dam	dʒa:m	dam	dam	dʒʋam	dʒam	dzam
house	hʌʉs	hʌʉt	hʌʉʝ	hʌʉd	hʌʉ	hʌʉs	hʌʉs	hʌʉs
path	paθ	pat	pa:t	paf	daf	pas	paf	pa:
door	dor	dɔr	dɔɪr	dɔɪr	dɔɪr	dɔɪr	dɔɪr	dɔ
smoke	smok	mot	smot	mot	soʔ	smot	smok	fod
bridge	brɪdʒ	bɪʒ	ʋɪdʒ	blɪd	bɪdʒ	bʋɪdz	bʋɪdz	brɪdz
train	tren	ten	ʃʋe:n	tlen	sen	tren	tʋen	tsen
chair	tʃer	tʃeɪr	tʃer	ter	ter	tʃer	teɪr	tser
red	rɛd	wɛd	ʋɛd	lɛd	ʋɛd	rɛd	wɛd	vɛd
spoon	spʉn	bʉn	çpʉ:n	pʉn	fʉn	spʉn	spʉn	fʉn
plane	plen	ben	fwen	plen	ten	plen	pwen	pwen
fly	flae	tae	fʋae	flae	fae	slae	flae	fwae
sky	skae	tae	stae	kae	sae	stae	stae	slae
sun	sʌn	dʌn	sʌn	dʌn	sʌn	sʌn	sʌn	sʌn
wing	wɪŋ	wɪŋ	wɪn	w͡vɪŋ	wɪnd	wɪn	wɪnz	wɪnz
splash	splaʃ	plats	swaʃ	plat	plas	splats	splas	fwas
tent	tɛnt	tɛnt	tɛnt	tɛnʔ	tɛnʔ	tɛnʔ	tɛnt	dɛnt
salt	sɔlt	dɔlt	çɔlt	tɔlt	dɔlt	sɔlt	sɔlʔ	sɔlʔ
crab	krab	dab	fʋab	klab	tad	trab	trab	dzab
sweet	swit	witi	switi	hwit	siʔ	switi	swiʔiz	sitiz
sleeve	sliv	lid	çjiv	siv	fibz	livz	sviv	siv
zip	zɪp	dɪp	tʝɪp	jɪp	zɪʔ	sɪp	zɪp	zɪp

Adult target-orthographic	Adult target - phonetic	P8	P9	P10	P11	P12	P13	P14
cup	kʌp	tʌʔ	dʌp	tʌp	dɔp	tʌʔ	dʌb	dʌp
gun	gʌn	dʌn	nʌn	tʌŋ	tɔŋ	dʌn	gʌn	-
knife	nʌɪf	nʌɪ:	dak	nʌɪt	nʌɪt	nʌɪʔ	nif	nʌɪk
sharp	ʃarp	ʃar	tap	ta:rp	tɔrp	tarʔ	da:p	ta:rp
fish	fɪʃ	çɪʔ	sit	tɪs	tɪt	bɪʔ	gɪs	pɪt
kiss	kɪs	tɪ	dɪðɪn	tɪ:s	tɪt	tɪʔ	dɪs	tɪt
sock	sɔk	ʃɔ	gɔk	tɔts	tɔt	tɪɔʔ	tɔʔ	sɔt
glass	glas	da	zap	das	dlat	daʔ	das	dla
watch	wɔtʃ	jɔ	-	jɔts	ɔt	wɔʔ	wɔts	wɔt
nose	noz	nod	dod	no:z	nɔd	no	noz	nɔd
mouth	mʌʉθ	nʌʉ	mʌʉ	mʌʉt	mʌʉt	mʌʉʔ	nʌʉf	mʌʉt
yawn	jɔn	jɔnɪn	nɔn	jɔ:	ɔn	ɔn	lɔn	nɔn
leaf	lif	jɪ	ji	jis	it	iʔ	tidʌ	lip
thumb	θʌm	tʌŋ	nʌm	dʌm	dʌm	bʌn	dʌm	fʌm
foot	fʉt	ʃʉ	dit	tʉt	dʉt	bɔʔ	tʉʔ	fit
toe	to	to	to	to	toz	to	toz	to
snake	snek	çnek	gek	nek	net	teʔ	dek	neɪt
van	van	dan	man	tan	ban	ban	ʋan	ban
fast	fast	da:t	dast	ta:s	taʔ	haʔ	gas:	fatər
girl	gɪrl	dɪjl	gɪl	dɪrl	dɪl	dɪrl	dɪwəl	dɪrəl
stairs	sterz	stejə	ser	terz	ter	ter	terz	teɪr
big	*bɪg*	dɪd	bɪ	bɪ:g	bɪd	bɪg	gɪ	bɪd
jam	dʒam	ʒan	*nan*	*dam*	*dam*	*dam*	*dam*	*dam*
house	hʌʉs	hʌʉ	hom	ʌʉs	ʌʉt	hʌʉ	hʌʉs	hʌʉt
path	paθ	pa:	pap	patswe	pat	baʔ	gaf	pat
door	dor	dɔɪr	dɔɪr	dor	dɔr	dɔr	dɔɪr	dɔɪr
smoke	smok	sno	bok	mok	mot	poʔ	tok	mot
bridge	brɪdʒ	dɪd	bɪd	bɪdz	bɪd	bɪh	gɪdz	brɪd
train	tren	ʃen	nen	ten	ten	ten	ten	ten
chair	tʃer	ʃeɪr	teɪr	ter	tɛr	tar	teɪr	teɪr
red	rɛd	jɛd	rad	rɛd	ɛd	waʔ	wɛd	rɛd
spoon	spʉn	dʉn	mʉn	pʉn	pʉn	pʉən	dʉn	pʉn
plane	plen	ten	nen	pen	pen	ben	den	pen
fly	flae	hae	tlae	tʃae	tae	pwae	dae	plae
sky	skae	hae	kae	stae	tae	tae	tae	-
sun	sʌn	çʌn	nʌn	dʌn	dʌn	tʌn	dʌn	tʌn
wing	wɪŋ	jɪn	wɪn	wɪŋt	wɪn	wen	wɪŋ	wɪn
splash	splaʃ	ʃaʔɪn	bat	pa:s	pat	pwaʔ	gas:	plat
tent	tɛnt	tɛn	tat	tʌɪt	tɛnt	tanʔ	dɛnt	tɛnt
salt	sɔlt	çɔl	dɔlt	dɔlt	dɔlt	tɔlʔ	gɔlʔ	tɔlʔ
crab	krab	jad	krap	tabs	tad	bʋaʔ	tab	tlab
sweet	swit	ʃiʔi	sit	witiz	titiz	piti	siti	siti
sleeve	sliv	çid	dit	tiz	tiv	tit	div	siv
zip	zɪp	ɪʔ	jɪp	vɪp	ɪp	dɪʔ	wɪp	dɪt

Appendix 7
Transcribed imitated utterances per subject

Broad phonetic transcription of the imitated utterances for all the normally developing and phonologically disordered children in the investigation

	Subject N1		
im 1	tʉ nɔtiz bɔɪz ər pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 3	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 4	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz ər pɪkɪŋ
	Subject N2		
im 1	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔtis bɔɪz wər pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 3	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 4	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz ər pɪkɪŋ
	Subject N3		
im 1	tʉ nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 3	tʉ nɔti bɔɪz ar itɪŋ sʌm pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 4	tʉ nɔti bɔɪz wər pɪkɪŋ	**im 8**	tʉ nɔti bɔɪ: ər pɪkɪŋ
	Subject N4		
im 1	tʉ lɪtəl bɔɪz ər pɪkɪŋ	**im 5**	tʉ lɪtəl bɔɪz hav bin pɪkɪŋ
im 2	tʉ lɪtəl bɔɪz ər pɪkɪŋ	**im 6**	tʉ lɪtəl bɔɪz hav bin pɪkɪŋ
im 3	tʉ lɪtəl bɔɪz ər pɪkɪŋ	**im 7**	tʉ lɪtəl nɔti bɔɪz hav bin pɪkɪŋ
im 4	tʉ lɪtəl bɔɪz əv bin pɪkɪŋ	**im 8**	tʉ lɪtəl nɔti bɔɪz hav bin pɪkɪŋ
	Subject N5		
im 1	tʉ nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪk	**im 7**	tʉ nɔti bɔɪz pɪkɪŋ
im 4	tʉ nɔti bɔɪz pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz pɪkɪŋ
	Subject N6		
im 1	tʉ nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz pɪkɪŋ
im 3	tʉ nɔti bɔɪz gɛtɪŋ	**im 7**	tʉ nɔti bɔɪz itɪŋ
im 4	tʉ nɔti bɔɪz pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz itɪŋ pɪkɪŋ
	Subject N7		
im 1	tʉ nɔti bɔɪd pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz pɪkɪŋ
im 4	tʉ nɔti bɔɪz pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz pɪkɪŋ
	Subject N8		
im 1	tʉ nɔti bɔɪz wər pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 3	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 4	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz ər pɪkɪŋ
	Subject N9		
im 1	tʉ nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 2	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪkɪ	**im 7**	tʉ nɔti bɔɪz ər pɪkɪŋ
im 4	tʉ nɔti bɔɪz ər pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz ər pɪkɪŋ

	Subject N10		
im 1	ðiz ɪz ðə nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪŋɪŋ	**im 7**	tʉ lɔti bɔɪz pɪkɪn
im 4	tʉ lɪtəl bɔɪz pɪŋɪŋ	**im 8**	tʉ nɔti bɔɪz pɪkɪn
	Subject N11		
im 1	nɔti bɔɪz pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz pɪŋkɪŋ
im 2	tʉ nɔti bɔɪz pɪkə	**im 6**	tʉ nɔti bɔɪz pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz pɪk
im 4	tʉ nɔti bɔɪz pɪkɪn	**im 8**	tʉ nɔti bɔɪz pɪkɪŋ
	Subject N12		
im 1	dʉ nɔti bɔɪz pɪkɪn	**im 5**	dʉ nɔti bɔɪz ər pɪkɪŋ
im 2	dʉ nɔti bɔɪs pɪkɪn	**im 6**	dʉ nɔti bɔɪz ər pɪk
im 3	dʉ nɔti bɔɪz ər pɪkɪŋ	**im 7**	dʉ nɔti bɔɪz ər pɪk
im 4	dʉ nɔti bɔɪz ər pɪkɪŋ	**im 8**	dʉ nɔti bɔɪz ər pɪk
	Subject N13		
im 1	tʉ nɔti bɔɪz wər pɪkɪŋ	**im 5**	tʉ nɔti bɔɪz pɪkɪn
im 2	tʉ bɔɪz pɪkɪŋ	**im 6**	tʉ nɔti bɔɪz pɪkɪn
im 3	tʉ bɔɪz pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz pɪkɪŋ
im 4	tʉ lɪtəl bɔɪz pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz pɪkɪŋ
	Subject N14		
im 1	tʉ nɔti bɔɪz pɪkɪn	**im 5**	tʉ nɔti bɔɪz pɪkɪŋ
im 2	tʉ nɔti bɔɪz pɪkɪn	**im 6**	tʉ nɔti bɔɪz ə pɪkɪŋ
im 3	tʉ nɔti bɔɪz pɪkɪŋ	**im 7**	tʉ nɔti bɔɪz pɪkɪŋ
im 4	tʉ nɔti bɔɪz pɪkɪŋ	**im 8**	tʉ nɔti bɔɪz pɪkɪŋ

	Subject P1		
im 1	ðe ʌr pɪkɪŋ	**im 5**	tʉ nɔti bɔɪ pɪkɪn
im 2	tʉ nɔti bɔɪ pɪʔɪn	**im 6**	tʉ nɔti bɔɪ pɪkɪŋ
im 3	tʉ tɔki bɔɪ pɪkɪn	**im 7**	tʉ nɔti bɔɪ pɪkɪŋ
im 4	tʉ nɔti bɔɪ pɪkɪn	**im 8**	tʉ nɔʔ bɔɪ pɪkɪŋ
	Subject P2		
im 1	tɔtɪ bɔɪʝ wə pɪtɪn	**im 5**	dʉ nɔti bɔɪʝ wər pɪtɪn
im 2	dʉ nɔwɪ vɔɪz wə pɪn	**im 6**	dʉ nɔti bɔɪʝ wər pɪtɪn
im 3	nɔtɪ bɔɪʝ wə pɪːn	**im 7**	ʉ nɔ bʷɔɪ ɪ pɪ
im 4	dʉ nɔti bɔɪʝ wə pɪʔɪn	**im 8**	dʉ nɔti bɔɪs wɛr pɪtɪn
	Subject P3		
im 1	ʉ n̥ɔʔɪ b̥ɔɪ iɪŋ	**im 5**	d̥ʉ n̥ɔdɪ b̥ɔɪd pɪkɪŋ
im 2	ʉ n̥ɔɪ b̥ɔɪ iɪŋ	**im 6**	n̥ɔdɪ b̥ɔɪd pɪkɪŋ
im 3	d̥ʉ n̥ɔɪ b̥ɔɪ iːŋ	**im 7**	d̥ʉ n̥ɔdɪ b̥ɔɪd pɪkɪŋ
im 4	d̥ʉ n̥ɔdɪ b̥ɔɪd ɪʔ pɪkɪŋ	**im 8**	d̥ʉ n̥ɔdɪ b̥ɔɪd pɪkɪŋ
	Subject P4		
im 1	tʉ nɔti bɔɪ fɪʔɪn	**im 5**	tʉ nɔti wɔɪ pfɪʔɪn
im 2	tʉ nɔti bɔɪ pɪʔn	**im 6**	tʉ mɔti bɔɪ fɪʔɪn
im 3	tʉ nɔti bɔɪz pɪʔɪn	**im 7**	tʉ nɔti bɔɪz pɪʔɪn
im 4	ʉ nɔti bɔɪz pɪʔɪn	**im 8**	tʉ nɔti bɔɪ pɪʔɪn
	Subject P5		
im 1	nɔti bɔiz pɪtɪn	**im 5**	tʉ nɔti bɔɪz pɪt
im 2	tʉ nɔti bɔɪs pɪtɪn	**im 6**	tʉ nɔti bɔɪz pɪtn
im 3	tʉ nɔti bɔɪz pɪŋ	**im 7**	tʉ nɔti bɔɪz pɪtn
im 4	tʉ nɔti bɔɪz pɪtəŋ	**im 8**	tʉ nɔti bɔɪz pɪtn

	Subject P6		
im 1	tʉ mɔʔi bɔɪz pɪkɪn	**im 5**	tʉ mɔti bɔɪz pɪkɪn
im 2	tʉ mɔti bɔɪz pɪkɪn	**im 6**	tʉ mɔti bɔɪz pɪkɪn
im 3	tʉ mɔti bɔɪz pɪkɪn	**im 7**	tʉ mɔti bɔɪz tekɪn
im 4	tʉ mɔti bɔɪz pɪkɪn	**im 8**	tʉ mɔti bɔɪz pɪkɪn
	Subject P7		
im 1	nɔdi bɔɪd wər pɪgɪn	**im 5**	tʉ lɪtəl nɔdi bɔɪd dər pɪdɪn
im 2	tʉ nɔdi bɔɪd wər pɪdɪn	**im 6**	tʉ nɔdi bɔɪd wər pɪdn
im 3	tʉ nɔdi bɔɪd wər pɪgɪn	**im 7**	tʉ nɔdi bɔɪd wər pɪdɪn
im 4	tʉ nɔdi bɔɪd wər pɪdɪn	**im 8**	tʉ ðə nɔdi bɔɪd wər pɪdɪn
	Subject P8		
im 1	nɔhi dai pɪhɪn	**im 5**	nɔhi daid tɪhɪn
im 2	nɔhi dai tɪhɪn	**im 6**	nɔhi daid tɪhɪn
im 3	nɔhi dai tɪhɪn	**im 7**	nɔhi daid nɪhɪn
im 4	nɔhi daid tɪhɪn	**im 8**	nɔhi daid tɪhaʉn
	Subject P9		
im 1	tʉ lɔti bɔɪ pɪki	**im 5**	dʉ nɔ bɔɪ pɪkin
im 2	tʉ tɔi bɔɪ pɪkin	**im 6**	dʉ dɔ bɔɪ pɪkin
im 3	tʉ nɔ bɔɪ pɪkiŋ	**im 7**	dʉ dɔ bɔɪ pɪkin
im 4	dʉ nɔ bɔɪ pɪkin	**im 8**	dʉ dɔ bɔɪ pɪkin
	Subject P10		
im 1	tʉ nɔti bɔɪz pɪkɪn	**im 5**	tʉ nɔti bɔɪz pɪkɪn
im 2	tʉ nɔti bɔɪz pɪkɪn	**im 6**	tʉ nɔti bɔɪz pɪkɪn
im 3	tʉ nɔti bɔɪd bɪkɪn	**im 7**	dʉ nɔti bɔɪz bɪkə
im 4	tʉ nɔti bɔɪz pɪkɪn	**im 8**	tʉ nɔti bɔɪz pɪkɪn
	Subject P11		
im 1	tʉ nɔti bɔɪz pɪkɪn	**im 5**	tʉ nɔti bɔɪ pɪkɪn
im 2	tʉ nɔti bɔɪz pɪkɪn	**im 6**	tʉ nɔti bɔɪ pɪtɪn
im 3	dʉ nɔti bɔɪ pɪkɪŋ	**im 7**	tʉ nɔti bɔɪ pɪkɪn
im 4	tʉ nɔti bɔɪ pɪkɪn	**im 8**	tʉ nɔti bɔɪ pɪtɪn
	Subject P12		
im 1	da nɔdi bɔɪ pɪtəŋ	**im 5**	tʉ nɔti bɔɪ pʷɪtɪn
im 2	tʉ bɔɪ pɪtəŋ	**im 6**	tʉ nɔti bɔɪ bɪtɪn
im 3	tʉ nːɔti bɔɪb pɪtɪn	**im 7**	tʉ nɔti bɔɪ bɪtɪn
im 4	tʉ nɔti bəba bɔɪː pɪtɪn	**im 8**	tʉ nɔti bɔɪ bɪtɪn
	Subject P13		
im 1	dɔɪ dɪkɪn	**im 5**	dɔɪ nɔʔi dɔɪ dɪm
im 2	gɔɪ dɔ ə dɔɪ	**im 6**	ðə mɔʔi dɔɪ dɪm
im 3	nɔʔi gɔɪz dɪʔən	**im 7**	gɔʔi dɔɪz dɪm
im 4	dʉ mɔʔi dɔɪ dɪʔən	**im 8**	nɔʔi dɔɪz dɪm
	Subject P14		
im 1	nʉ nɔʔi dɔɪd	**im 5**	bɔɪ plɪʔ də
im 2	tʉ lɪʔl bɔɪ dɪʔ wə	**im 6**	tʉ lɪtəl bɔɪd pɪʔ
im 3	tʉ lɪʔl bɔɪ mɪʔ nə	**im 7**	tʉ lɪʔəl bɔɪd pɪʔ
im 4	lɪʔl bɔɪ baːd	**im 8**	dʉ lɪʔəl bɔɪd

Appendix 8
Transcribed spontaneous utterances per subject

Broad phonetic transcription of the spontaneous utterances for all the normally developing and phonologically disordered children in the investigation

	Subject N1		
sp 1	ðə trenz gɔɪŋ θrʉ ðə	**sp 5**	hiz səpozd tə bi ɔn hɪz o:n
sp 2	ən nʌʉ hiz wekin ʌp	**sp 6**	tɔməs ɪz ɔlrɛdi sad
sp 3	kɔz hiz sejɪŋ kʌm ɔn wek ʌp	**sp 7**	ðer dʒʌst tekɪŋ ðem tə ðə plesɪs
sp 4	ʌi θɪŋk hiz stɪl lʉkɪŋ	**sp 8**	bikɔz ðen ðel bi ɪn ðer stɪl
	Subject N2		
sp 1	wʌɪndɪŋ hɪz ʌɪjz	**sp 5**	ðer gɔɪn ðu ðə brɪdʒ
sp 2	hiz ɪn ðə stesʃən	**sp 6**	kɔz hi kɔz tɔməs wə bin tʃiki
sp 3	hiz gɪnə seɪ jʉr a leɪ:zi bonz	**sp 7**	hiz goɪŋ ɔn ðə rʌʉndəbʌʉt
sp 4	hiz havɪn a bad fes ɔn	**sp 8**	hiz gɔnə mʉv ɔf
	Subject N3		
sp 1	hiz dʒʌst ə ɔʔ duɪn ðaʔ	**sp 5**	jʉ kən tɛl hɪm ɪʔ
sp 2	ðə mʌʉs ɪz ɔn ðat	**sp 6**	bʌʔ hi kən wɔtʃ ɪt
sp 3	ʌɪ don rirɪ lʌɪl ðaʔ bɪd	**sp 7**	ʌɪ kant rimɛmbər ɪt
sp 4	nɔ bʌʔ ʌi wɔnt tə siʔ ɔn jʉ	**sp 8**	jɛ ən ʌɪ kən pleən əʔ
	Subject N4		
sp 1	wae ɪʔ ɪt kwæət	**sp 5**	ðe gɔɪn bak tə ðə ʌnər steʃɪn
sp 2	ən gɔrdənz bin pʉɪŋ hɪm ʌlɔŋ tʉ fast	**sp 6**	ɪts nɔʔ mʉvɪŋ kɔz ɪts ðə trenz
sp 3	nʌʉ hiz angwɪ	**sp 7**	nʌʉ hiz tʌŋɪn ɒʌʉnd
sp 4	ən tɔməs ɪz tʉ tʌird	**sp 8**	ɔl ðə pipl ər lafɪŋ at hɪm
	Subject N5		
sp 1	ənʌðər trenz	**sp 5**	kan rimɛmbər
sp 2	hiz nɔʔ goɪŋ bak	**sp 6**	bla:k jɛlɔ pɪŋk grin
sp 3	tə tek ɪʔ əweɪ	**sp 7**	kɔz ɪtz hɔt
sp 4	ʌndər ðə tʌnəl	**sp 8**	mʌi sɔks gɔʔ wɛʔ
	Subject N6		
sp 1	bʌt ʌɪ dʒʌst gɔʔ nɔʔ gɔt ðə sem əz ðə t wʌn	**sp 5**	pʉʃd ðə nɔti karɪdʒəz
sp 2	ənd sʌmtʌimz hi bi tʃiki tə gɔrdən	**sp 6**	ən ðen hi bi tʃiki tə gɔrdən
sp 3	hi goz bakwərdz tə gɛʔ ðə karɪdʒəz	**sp 7**	teks hɪm bak tʉ hɪz steʃɪn
sp 4	tʃiki ət ðə karɪdʒəz	**sp 8**	ðe wər gɔɪn so fast hiz rʌn ʌʉt ɔv stim
	Subject N7		
sp 1	ðerz tɔməs ðə taŋk agɛn	**sp 5**	em hi pʉlz hɪm fast
sp 2	wʌi ər ðe goɪn verɪ fast	**sp 6**	ɪz ðər ɛnɪ moɪr stɔrəz
sp 3	ən tɔməs sɛd wek ʌp lezi bonz	**sp 7**	hi goz ə ðə tʌrntebɪl
sp 4	hiz gɔɪn tə se ðat	**sp 8**	tʃikɪ tə gɔrdən ʌgɛn
	Subject N8		
sp 1	ən ðats gɔɪn tʉ fas fər tɔməs	**sp 5**	bikɔz ʌɪ θɪŋk hi dʌznt wɔnt
sp 2	hi sɛd wek ʌp lezi bonz	**sp 6**	gɛrɪŋ sʌm moɪr wɔtər
sp 3	bʌt lʉk hiz gɔʔ bak ɪn	**sp 7**	bikɔz ʌi fɪŋk hiz bin dɔɪŋ
sp 4	gɔrdən mʌit bi pʉlɪŋ	**sp 8**	rʌnɪŋ so fat ðat hi kanʔ dʉ ɪt
	Subject N9		
sp 1	ad bi kwʌiʔ dɪfɪkʌlt	**sp 5**	hi sɛd no hi kʉdənʔ
sp 2	hiz kʌmɪn tə ðə steʃɪn	**sp 6**	jɛ ə nʌn fər gɔrdən
sp 3	jɛ:s ðats ʌ fʌnə we ɪs ə bɪʔ dɪfɪkʌlt	**sp 7**	wel ɪs hard tə tel ðə stori wɛn jə kan lɪ sənə
sp 4	θɪŋk hiz slipɪŋ ʌgɛn	**sp 8**	nʌʉ ʌer djə fɪŋk ðər gɔɪn

	Subject N10		
sp 1	puʃɪŋ ðə karəz	**sp 5**	luk ə ðem hiz tʌird ʌut
sp 2	hi sɛd trʌi ən katʃ mi wek ʌp	**sp 6**	hiz gɔɪn θru ðə brɪdʒ
sp 3	hi wɔnts hɪs karɪdʒəz	**sp 7**	gɔɪn bak tə ðə steʃɪn
sp 4	nʌu kən ju pul ɪʔ ʌp ə bɪʔ	**sp 8**	wɛl fɪrst jə haf tə tek ðis θɪŋ ɔf
	Subject N11		
sp 1	tɔməs ðə taŋk ɛndʒɪn wɔz stʌk	**sp 5**	wɛnt hiz goɪn tə du ɪz slip
sp 2	hiz goɪn rʌun ən rʌun ɔntə ðə steʃɪŋ	**sp 6**	werzə ðə bɔs ɔv ðə tren
sp 3	ʌiv gɔʔ ʌ lɪtəl tɛdi ber ɔn mʌi herban d	**sp 7**	no wɔt wɛnz ðis wʌn fɪnɪʃ o jɛ ʌi rimɛ mbər
sp 4	hi kant hiz gɛtɪŋ stʌk ʌgɛn	**sp 8**	ðer aʔ ðə steʃɪn
	Subject N12		
sp 1	hi dʌzən bɛnd hɪz lɛgz	**sp 5**	ʌi wɔnʔ ə drɪnk ɔ dʒus
sp 2	hiz puʃɪŋ hɪm ɪn ðə brɪdʒ		
sp 3	hʌu kən tɔməs bi stʌk ɪn ðer		
sp 4	hiz nɔʔ goɪn tə hʌv enɪfɪŋ		
	Subject N13		
sp 1	ʌi don no ðə storɪ	**sp 5**	gɔrdən ən ðərz tɔməs
sp 2	ðe: ən ðerz ðə drʌivər	**sp 6**	er goɪn rʌund ðə relwe trak
sp 3	hi goɪn past ðer tɔməs	**sp 7**	ən nʌu hiz goɪn θru ə tʌnəl
sp 4	nʌu hiz gɔɪn fɔrwərd	**sp 8**	so hiz gɛʔɪn gɔrdən tə pul hɪm
	Subject N14		
sp 1	ən tɔməs ɪz wekɪn hɪm ʌp	**sp 5**	hiz biɪn tʃiki nʌu
sp 2	tɔməs ɪz stɔpɪŋ ən ðen hiz goɪn slo	**sp 6**	ðər ʌndər ʌ tʌnəl
sp 3	tɔməs ɪz lɛdɪ fər hɪz plan	**sp 7**	hɪkɔz ðle go ovər blɪdʒɪz
sp 4	hiz tuk ʌ bɪʔ nʌu ɪʔs gɔɪn	**sp 8**	nʌu hiz gɔɪn ɔn ðə tebɪl

	Subject P1		
sp 1	ən ðə pɔrtən ən tɔmət	**sp 5**	wɛl hid do hi doɪŋ ʌndər ðə tʌŋɪl
sp 2	ənd ʌi tən ti ɔl ðə te:ɪnt mudɪŋ	**sp 6**	wɪʔ tɔmət ən hi doɪn tu da:t
sp 3	ən hi dɛd wek ʌp lɛdɪ bond	**sp 7**	ən wɪl gɛt ðəm ɪn ʌut ɔ ðə bak
sp 4	hi ɪʔ detɪŋ angri ʌde:n	**sp 8**	tən wi du ʌdər wʌn
	Subject P2		
sp 1	tu ə stesən az wɛl	**sp 5**	ça hi hɪŋɟ ɪt hʌni
sp 2	hi ʃe weʔ ʌʔ lezə bonz	**sp 6**	ðə əʔ stɔpɪn ət ə steʃən
sp 3	hiz hɪnkɪn tə pul hɪm ʌut	**sp 7**	ba tə hɪ hʌuʔ tə ha ə dʒɪn
sp 4	ðeʔ ʌndə ə tʌnəl	**sp 8**	bi tʃiki tə dɔrdən adɛn
	Subject P3		
sp 1	hi goɪn tə gɛt gɔdən a rɛt ʌi fɪnk	**sp 5**	ən ðen gordən go tu dast də tɔmət
sp 2	hid wɪkən lɛlɪ hard	**sp 6**	ðer goɪn dlu ðə tʌnəl
sp 3	n:ul ɔləm bɪg ɛndənt	**sp 7**	goɪn ʌklɔs ðə blɪdʒ
sp 4	gɔrdən doɪnz ɪntə ðə tlen	**sp 8**	hi god baʔ tə ðə steʃən
	Subject P4		
sp 1	tɔməd də tant ɛndən	**sp 5**	hi tʌnɪn ən tʌnɪn
sp 2	hi ful hi ʌndən	**sp 6**	donʔ rendər ʌivər
sp 3	jə ɛnd ən də go fatər ə fatər	**sp 7**	ʌi fɪŋk hiz go tə də ʌdər wʌn
sp 4	tə də ʌdər steʃən dɪn	**sp 8**	ɪʔ həz tə bi bɪdə ə bɪdə
	Subject P5		
sp 1	bʌʔ ʌi dɔt tɔməs ʌ bɪdio wɔz ɔn ən ɔ nən	**sp 5**	hɪz dɔrdən pus baʔwərdz
sp 2	bʌʔ ʌi dɔʔ ɔl ʌs dəm	**sp 6**	wi has put ɪt dʌun əbɪʔ
sp 3	wen ðə ɛndʒənz ar ɪl	**sp 7**	hɛnri dets stʌt ɪn ðə tʌnəl
sp 4	hiz apɔrtənt ɪndən	**sp 8**	hiz ɔn ðə tʌrntebɪl

	Subject P6		
sp 1	hi sɛd ə tranʔ tatʃ mi	sp 5	ɛn hiz doɪn ovər ðə tʌnəl
sp 2	hi əz dɛʔɪn tʌird	sp 6	hiz dɔn fɔrwərd ən tɔməs wɪl əstip
sp 3	doz bak ɪntə ðə stesɪn	sp 7	ɪn ə tʌn fɪn fɪn
sp 4	tɔz hil hiz pʉlɪn tɔməs	sp 8	tɔz gʉz bin bizə
	Subject P7		
sp 1	ʌm mʌi dadi has bin	sp 5	bʊɪdz ɪz doɪn ovər ðə wɔdər
sp 2	ʌndɪl aftər aʔ lʌnstʌim	sp6	wʌi ɪz hi dʌs ɪt do noʌer
sp 3	ənd dɔrdənz sɪvi ɪznt hi	sp 7	mʌi fevrɪt wən hi wəz
sp 4	wɛn hi dʌz do bat dʌʉn ðer	sp 8	mʌi bɛst wɪdio ɪz
	Subject P8		
sp 1	neja anʌʔ jʌŋ		
sp 2	wijɪ wijɪ tʌijə		
sp 3	dɪhəhən ən dɪnjən		
sp 4	ən ʌi si a jaf		
	Subject P9		
sp 1	pʉtɪn nʌnər wʌn	sp 5	nɛn tɔmt: tanɪn
sp 2	de meki ʌp ʉ tapɪl mɔn	sp 6	sawɪn pʉn ɪn tət tɛstɪn
sp 3	mɑn cɔtɔn ne nen	sp 7	tɔtəp pem ɔm ə pet
sp 4	sʌmwʌn pʉ san ʌʉt nə tetɪn		
	Subject P10		
sp 1	har wʌr dʉ ɪt lʌiʔ mi		
sp 2	ɔh dɛs dɛt ɔl ðə we		
sp 3	ɔn dʌ jʌʉn ən jʌʉndʌbʌʉt		
	Subject P11		
sp 1	tɔmət də tan ɛndɪn	sp 5	hi hə tə do baʔ ɔn
sp 2	da dʉ ə dət ə tɔmət		
sp 3	da ɛndən nɔ də ta:rt		
sp 4	tɔmət no pot tə bi der		
	Subject P12		
sp 1	tɔn məmbər wət ɪʔ ɪ	sp 5	ðe jɔ at tə teʔɪn
sp 2	ən dəd dəʊl tʌʊɪn ɪʔ	sp 6	ən ðon dɔwɪn tɪ do tʉ tih
sp 3	də dəʊl dʌnɪŋ dʌʉn də teɪr		
sp 4	ʔə tən dowɪn owər ðə bɪh		
	Subject P13		
sp 1	tʉ dʉ ten ən ðə wod	sp 5	də tʉ dʉ ten nɪnʔ te hɪm no niz
sp 2	ʌi θin tə ɪna tɔməs	sp 6	hi wɔk ʌn tʉ dʉ ten
sp 3	nas dɪm ɪt tɔp at də testɪn	sp 7	daʔ kawɪdʒ ɪʔ tɔp ɪʔ teʃɪn
sp 4	hi dod bakwədz hi tɛtɪn ðaʔ	sp 8	dən ən də gɪdʒ ʌdʌid də wɔʔər
	Subject P14		
sp 1	əm nɔʔ dʉn ðə rʌiʔ we	sp 5	ʌm dʉntə ɔl ʌdɛn
sp 2	ən ða ə pɪtər tʉ vɪd ən ʌ bʉ	sp 6	tanta tlɔt ə mʌi hʌʉ
sp 3	ʌ sin ðə ʌlər wʌn	sp 7	ən hɪm nɔ tʌmə rʌʉn tə jiurt
sp 4	ða ʌ bɔɪ ən ðə a bɔɪ	sp 8	ʌn dɔ fle pletə ʌdɛn

Appendix 9
Articulation rate data per subject

N1	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms) (ms)	Number of segments	Number of syllables	Articulating time(ms)
1	18	7	2160	16	6	2365
2	17	7	2050	15	6	1329
3	17	7	1870	20	8	1833
4	17	7	1950	18	6	1682
5	17	7	1833	20	8	2114
6	17	7	1853	16	7	2271
7	17	7	1784	25	9	3969
8	17	7	1564	22	8	2794
Mean	17.13	7	1883	19	7.25	2295
Mean articulation rate per s	9.16 seg/s	3.75 syll/s		8.79 seg/s	3.37 syll/s	

N2	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	17	7	1674	13	5	1899
2	19	7	2051	13	5	1471
3	17	7	1782	21	9	3009
4	17	7	1756	17	7	2409
5	17	7	1622	15	6	1524
6	17	7	1668	22	9	2668
7	17	7	1652	20	8	2962
8	17	7	1630	12	5	1228
Mean	17.25	7	1729	16.63	6.75	2146
Mean articulation rate per s	10.00 seg/s	4.07 syll/s		8.04 seg/s	3.25 syll/s	

N3	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	14	6	1307	17	7	2937
2	14	5	1209	13	5	1750
3	24	10	2262	18	7	1552
4	18	7	1646	17	8	2314
5	17	7	1589	12	5	1234
6	17	7	1636	12	5	1894
7	17	7	1763	15	7	1765
8	16	7	1613	15	7	1363
Mean	17.13	7	1628	14.88	6.38	1851
Mean articulation rate per s	10.56 seg/s	4.30 syll/s		8.47 seg/s	3.63 syll/s	

N4	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	18	7	1833	11	5	887
2	18	7	1586	29	11	3761
3	18	7	1629	11	4	1459
4	21	8	1728	16	6	2095
5	21	8	1709	23	9	1844
6	21	8	1773	23	15	5255
7	25	10	2146	16	5	1529
8	25	10	2346	20	9	1803
Mean	20.88	8.13	1843	18.63	8	2329
Mean articulation rate per s	11.35 seg/s	4.41 syll/s		9.21 seg/s	3.77 syll/s	

N5	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	1393	11	3	2226
2	15	6	1098	12	5	1398
3	13	5	820	10	5	804
4	15	6	993	12	5	927
5	15	6	1375	11	4	1254
6	15	6	1236	16	5	3880
7	15	6	1264	9	3	806
8	15	6	1483	11	4	2445
Mean	14.75	5.88	1208	11.50	4.25	1717
Mean articulation rate per s	12.55 seg/s	4.99 syll/s		8.43 seg/s	3.30 syll/s	

N6	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	1352	29	11	2673
2	15	6	1368	27	10	3404
3	15	6	1487	26	10	2858
4	15	6	1492	15	7	2051
5	15	6	1420	17	7	2667
6	15	6	1323	21	12	3488
7	14	6	1175	20	7	1827
8	19	8	1692	30	10	3316
Mean	15.63	6.25	1414	23.13	9.25	2785
Mean articulation rate per s	11.08 seg/s	4.43 syll/s		8.45 seg/s	3.36 syll/s	

N7	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	15	6	1454	19	6	1861
2	15	6	1556	19	7	1767
3	15	6	1606	23	9	2274
4	15	6	1514	14	6	1399
5	17	7	1625	14	6	2509
6	15	6	1297	17	7	1766
7	15	6	1480	17	8	2390
8	15	7	1571	16	7	1933
Mean	15.25	6.25	1513	17.38	7	1988
Mean articulation rate per s	10.11 seg/s	4.14 syll/s		8.96 seg/s	3.59 syll/s	

N8	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	18	7	1601	24	9	2615
2	17	7	1514	18	7	2156
3	17	7	1625	17	6	1549
4	17	7	1630	17	6	1518
5	17	7	1544	22	9	1452
6	17	7	1546	16	6	1697
7	17	7	1460	21	8	2567
8	17	7	1640	21	9	3027
Mean	17.13	7	1570	19.50	7.50	2073
Mean articulation rate per s	10.92 seg/s	4.47 syll/s		9.92 seg/s	3.79 syll/s	

N9	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	15	6	1315	16	6	2024
2	17	6	1599	18	7	1984
3	14	5	1293	26	13	3928
4	17	6	1249	17	6	1389
5	17	7	1493	14	6	1781
6	17	6	1325	15	6	1697
7	17	6	1518	35	13	3212
8	17	6	1779	20	7	1277
Mean	16.38	6	1446	20.13	8	2161
Mean articulation rate per s	11.43 seg/s	4.19 syll/s		9.89 seg/s	3.82 syll/s	

N10	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	20	8	2409	12	5	1550
2	15	6	1691	22	8	2733
3	15	6	1911	17	6	1610
4	16	6	1702	17	8	1410
5	15	6	1904	18	6	2004
6	15	6	1692	17	6	1558
7	15	6	1764	17	6	1668
8	15	6	1620	20	9	2571
Mean	15.75	6.25	1837	18.25	6.75	1888
Mean articulation rate per s	8.62 seg/s	3.42 syll/s		9.83 seg/s	3.69 syll/s	

N11	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	13	5	1360	23	8	2270
2	14	6	1359	28	10	3755
3	15	6	1391	30	12	1898
4	15	6	1432	23	8	3337
5	16	6	1861	21	8	2410
6	15	6	1389	18	6	2222
7	13	6	1744	30	13	3356
8	15	6	1345	12	6	1531
Mean	14.50	5.88	1485	23.13	8.88	2597
Mean articulation rate per s	9.89 seg/s	4.00 syll/s		9.23 seg/s	3.59 syll/s	

N12	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	15	6	1482	18	6	1931
2	15	6	1330	19	7	2339
3	17	7	1404	22	8	2315
4	17	7	1230	20	9	1462
5	17	7	1552	15	6	1862
6	15	6	1366	-	-	-
7	15	6	975	-	-	-
8	15	6	1999	-	-	-
Mean	15.75	6.38	1417	18.80	5.2	1982
Mean articulation rate per s	11.52 seg/s	4.66 syll/s		9.74 seg/s	3.79 syll/s	

N13	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	18	5	1030	14	6	1498
2	11	4	825	17	6	2316
3	11	4	1158	18	6	1566
4	16	6	1486	17	6	1602
5	15	6	1342	17	6	1317
6	15	6	1478	22	7	2095
7	15	6	1100	21	8	1929
8	15	6	1441	23	9	1888
Mean	14.50	5.38	1232	18.63	6.75	1776
Mean articulation rate per s	12.06 seg/s	4.42 syll/s		10.66 seg/s	3.87 syll/s	

N14	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	15	6	1362	19	8	2474
2	15	6	1839	28	10	2859
3	15	7	1686	21	8	2187
4	15	6	1328	19	8	1849
5	15	6	1565	14	6	1281
6	16	7	1485	14	6	1519
7	15	6	1368	19	8	1927
8	15	6	1354	19	8	2209
Mean	15.13	6.25	1498	19.13	7.75	2038
Mean articulation rate per s	10.22 seg/s	4.21 syll/s		9.49 seg/s	3.89 syll/s	

P1	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	9	4	890	17	7	2831
2	13	6	1453	24	9	4162
3	14	6	1442	20	8	2898
4	14	6	1296	17	8	2466
5	14	6	1389	26	11	4351
6	14	6	2052	21	9	3631
7	14	6	1348	22	9	2721
8	12	6	1126	14	7	1814
Mean	13.00	5.75	1374	20.13	8.5	3109
Mean articulation rate per s	9.69 seg/s	4.30 syll/s		6.64 seg/s	2.85 syll/s	

P2	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	1229	14	6	1996
2	15	6	1318	15	7	2276
3	13	5	1477	18	7	2639
4	16	7	1348	12	6	1711
5	18	7	1582	14	6	2236
6	18	7	2128	18	8	2883
7	9	5	1465	18	8	2747
8	18	7	1594	18	8	1769
Mean	15.25	5.38	1518	15.88	7	2282
Mean articulation rate per s	10.19 seg/s	4.36 syll/s		7.08 seg/s	3.14 syll/s	

P3	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	10	6	945	26	6	1705
2	10	5	982	16	6	1248
3	10	6	1127	16	7	2075
4	16	7	1366	21	7	1650
5	15	6	1004	26	10	2209
6	13	5	1153	17	6	1102
7	15	6	1079	15	6	973
8	15	6	1159	17	7	1354
Mean	13	6	1102	19.25	6.88	1539
Mean articulation rate per s	11.8 seg/s	5.37 syll/s		12.96 seg/s	4.66 syll/s	

P4	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	14	6	1263	16	6	1766
2	14	5	1387	12	5	1814
3	13	6	1510	22	10	2059
4	15	6	1306	17	7	2218
5	14	6	1374	14	6	1828
6	14	6	1560	14	6	1501
7	15	6	1309	22	9	2208
8	14	6	1621	17	9	2058
Mean	14.38	5.88	1416	16.75	7.25	1931
Mean articulation rate per s	10.23 seg/s	4.18 syll/s		8.65 seg/s	3.74 syll/s	

P5	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	13	5	1310	29	14	3615
2	15	6	1145	13	6	1456
3	13	6	1266	15	6	1947
4	15	5	1081	16	6	1556
5	13	5	1176	19	7	1628
6	14	5	1031	17	7	1443
7	14	5	1031	22	10	2636
8	14	5	1200	16	6	1439
Mean	13.88	5.13	1155	18.38	7.75	1965
Mean articulation rate per s	12.13 seg/s	4.47 syll/s		9.73 seg/s	4.01 syll/s	

P6	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	15	6	1451	15	6	2323
2	15	6	1520	13	6	1286
3	15	6	1393	18	7	2184
4	15	6	1309	19	7	2214
5	15	6	1379	19	8	1769
6	15	6	1317	28	10	3988
7	15	6	1716	12	6	2630
8	15	6	1413	13	5	1518
Mean	15	6	1437	17.13	6.88	2239
Mean articulation rate per s	10.51 seg/s	4.20 syll/s		8.03 seg/s	3.28 syll/s	

P7	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	16	6	1509	15	6	1799
2	18	7	1505	19	7	1830
3	18	7	1767	20	7	2158
4	18	7	1309	20	7	2129
5	23	11	4407	21	8	2199
6	17	8	2981	19	8	2302
7	18	7	1912	17	6	1381
8	20	8	2268	14	5	1922
Mean	18.50	7.63	2207	18.13	6.75	1965
Mean articulation rate per s	9.46 seg/s	3.79 syll/s		9.35 seg/s	3.47 syll/s	

P8	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	12	5	1279	10	6	2448
2	12	5	1214	13	6	2103
3	12	5	1177	15	6	1999
4	13	5	1116	10	6	1730
5	13	5	1351	-	-	-
6	13	5	1151	-	-	-
7	13	5	1301	-	-	-
8	14	5	1625	-	-	-
Mean	12.75	5	1277	12	6	2070
Mean articulation rate per s	10.08 seg/s	3.97 syll/s		5.89 seg/s	2.94 syll/s	

P9	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	13	6	1512	13	6	1300
2	12	5	1412	17	6	2575
3	12	5	1277	13	6	1644
4	12	5	1683	21	8	2945
5	12	5	1326	12	6	1587
6	12	5	1257	19	8	2158
7	12	5	1231	14	6	2136
8	12	5	1700	-	-	-
Mean	12.13	5.13	1425	15.57	6.57	2049
Mean articulation rate per s	8.63 seg/s	3.64 syll/s		7.79 seg/s	3.37 syll/s	

P10	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	2845	15	6	2434
2	15	6	2288	13	6	2199
3	15	6	1915	20	7	4771
4	15	6	1837	-	-	-
5	15	6	1828	-	-	-
6	15	6	1540	-	-	-
7	15	6	1481	-	-	-
8	15	6	1617	-	-	-
Mean	15	6	1919	16	6.33	3135
Mean articulation rate per s	8.85 seg/s	3.26 syll/s		5.92 seg/s	2.39 syll/s	

P11	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	1793	15	6	2237
2	15	6	1486	14	7	2515
3	14	6	1367	15	7	2466
4	14	6	1683	17	9	2628
5	14	6	1612	12	6	1494
6	14	6	1478	-	-	-
7	14	6	1969	-	-	-
8	14	6	1798	-	-	-
Mean	14.25	6	1648	14.60	5	2268
Mean articulation rate per s	8.76 seg/s	3.69 syll/s		6.57 seg/s	3.15 syll/s	

P12	Imitated connected speech			Spontaneous connected speech		
Utterance	Number of segments	Number of syllables	Articulating time(ms)	Number of segments	Number of syllables	Articulating time(ms)
1	15	6	2592	14	6	2197
2	16	4	1751	15	7	2392
3	15	6	3017	21	7	2630
4	18	7	3058	17	8	2361
5	14	6	2155	12	6	1686
6	14	6	1916	18	8	3375
7	14	6	2299	-	-	-
8	14	6	2074	-	-	-
Mean	15	5.88	2358	16.17	7	2440
Mean articulation rate per s	6.55 seg/s	2.54 syll/s		6.71 seg/s	2.94 syll/s	

P13	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	8	3	863	14	7	2260
2	9	4	1466	15	6	1708
3	12	5	1538	21	8	3381
4	12	6	1638	20	8	2648
5	12	5	1649	22	9	2671
6	11	5	1509	14	7	1704
7	10	4	1232	17	8	3358
8	10	4	1191	20	9	2306
Mean	10.50	4.50	1386	17.88	7.75	2504
Mean articulation rate per s	7.70 seg/s	3.26 syll/s		7.37 seg/s	3.22 syll/s	

P14	Imitated connected speech			Spontaneous connected speech		
Utterance	**Number of segments**	**Number of syllables**	**Articulating time(ms)**	**Number of segments**	**Number of syllables**	**Articulating time(ms)**
1	9	4	1203	14	6	1211
2	12	6	1208	20	10	2286
3	12	6	1434	13	6	1075
4	9	4	1342	14	7	2662
5	8	3	1365	13	6	1488
6	13	5	1228	16	6	1307
7	12	5	1031	21	8	1671
8	10	4	882	16	7	1785
Mean	10.63	4.63	1212	15.88	7	1686
Mean articulation rate per s	8.99 seg/s	3.89 syll/s		10.02 seg/s	4.36 syll/s	

Appendix 10
Accurately produced DDK rate measures

1. Rate from end of first syllable to end of sixth syllable (column "1-6")
2. Rate from end of first syllable to end of penultimate syllable (column "1-end")

Subject	[pə]		[tə]		[kə]		[pətə]		[pətəkə]	
	1-6	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**
N1	3.54	3.72	3.71	3.67	3.14	3.22	3.84	3.97	3.17	3.09
N2	4.04	3.96	4.11	3.99	3.69	3.62	4.26	4.25		
N3	4.80	4.82	4.75	5.05	4.13	4.17	4.59	4.74	4.12	4.02
N4	4.05	3.96	3.89	3.85	3.46	3.43	4.63	4.43	3.82	3.59
N5	3.50	3.48	3.54	3.54	3.47	3.45	3.57	3.41		
N6	3.52	4.30	4.56	4.70	3.55	3.85	3.99	4.09	4.12	4.36
N7	3.59	3.65	3.79	3.62	4.02	4.02	4.71	4.53	4.43	4.37
N8	3.72	3.78	3.54	3.53	3.59	3.44	4.66	4.46	4.44	4.34
N9	4.07	4.01	4.10	4.15	3.08	3.41	5.50	5.16	3.35	3.32
N10	4.33	4.33	4.16	4.06	4.02	3.95	4.55	4.30	3.17	3.32
N11	4.42	4.29	4.47	4.40	4.08	4.27	4.69	5.15		
N12	4.07	3.96	3.55	3.37	4.17	4.19	3.58	4.15	2.71	2.02
N13	3.88	3.93	3.70	3.47	3.41	3.26	4.81	4.61		
N14	4.11	4.16	4.21	4.46	3.41	3.86	6.55	6.62	3.31	3.32
Group Mean	4.00	3.98	4.01	3.99	3.66	3.72	4.57	4.56	3.60	3.57

Subject	[pə]		[tə]		[kə]		[pətə]		[pətəkə]	
	1-6	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**	**1-6**	**1-end**
P1	2.84	2.98					5.60	4.38		
P2	4.05	4.18	4.60	4.90			5.06	5.03		
P3	4.88						5.03	5.02		
P4	3.36	3.60	3.39	3.24			3.81	3.64		
P5	4.22	4.11	4.38	4.38			4.48	4.20		
P6	3.90	4.08	4.02	3.98	3.72	3.17	4.96	4.72		
P7										
P8	3.97	3.93	4.15	4.07						
P9	3.80	3.78	3.06	3.01	2.62	2.73	3.15	3.10		
P10	4.31	4.28			3.6	3.67				
P11	4.15	4.08	4.70	4.26						
P12	2.91	3.08	3.22	3.24	2.61	2.61			2.65	3.01
P13	3.30	3.24	3.18	2.24	3.01	2.87				
P14	3.77	4.01	4.75	4.75						
Group Mean	3.80	3.78	3.95	3.97	3.11	3.01	4.58	4.35	2.65	3.01

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